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CASUALTY EVACUATION AND DISTRIBUTION

USING B-767 AND C-9 AIRCRAFT

THESIS

William B. Ewing, Jr.
Major, USAF

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

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William B. Ewing, Jr.

Major, USAF

March 1986

PREFACE

The purpose of this study was to develop an alternative system to the present plan for evacuating and distributing casualties resulting from a conventional European conflict. The proposed system requires modified Boeing-767 aircraft, as part of the Civil Reserve Air Fleet (CRAF), to perform the intertheater evacuation mission. The C-9 Nightingale aircraft would distribute casualties from a single B-767/C-9 interface location. The plan relieves the C-141 Starlifter of all evacuation commitments so that it may be dedicated to the resupply effort.

I wish to thank many people who have contributed so much to this research. These include Dr. Jeffrey Kennington (Department of Operations Research, Southern Methodist University, Dallas, Texas), Mrs. Georgie Thomas (Department of Health and Human Services, Rockville, Maryland) and TSgt. Linnes Chester (Medical Readiness Division, Fort Sam Houston, Texas). I am very grateful to Capt. Robert Chmielewski and Maj. Robert Murray at MAC's Operations Research Division and Surgeon General's Office, respectively, for their time, research data and recommendations for this study. Their insight greatly increased my understanding of the problems of this real-world possibility.

Special thanks are extended to Capt. Joseph Litko, my thesis advisor, who was always available to guide me through those difficult times. His wisdom, encouragement and recommendations made this thesis possible. Thank you, Joe.

William B. Ewing, Jr.

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Abstract

The objective of this ~~research~~ thesis was to develop and evaluate a casualty evacuation and distribution system using B-767 and C-9 aircraft. For a European conventional conflict, an average casualty rate between 1600 and 1900 per day was considered for a 60-day period. Casualties were distributed among all potential members of the National Disaster Medical System. The system was modelled using SLAM simulation and FORTRAN computer code.

The performance of the system was measured by the average time each patient spent in the evacuation system, beginning with the time the patient was released (medically cleared) to fly. The time ended when the patient arrived at the final destination airport. The factors in the model affecting the mean time in the system (TIS) include pre-departure ground time, flying time, number and capacity of aircraft and casualty rate.

Response surface equations were generated from the experimental results for selected combinations of factor levels. The prediction equations provide an accurate measure of the performance of the system, while saving the time and expense of conducting simulation experiments. The equations can be used to determine either the required number of aircraft or the necessary aircraft capacity given a specified criterion value of mean TIS and expected casualty rate. Keywords:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The objective of this research was to develop and evaluate a casualty evacuation and distribution system using B-767 and C-9 aircraft. For a European conventional conflict, an average casualty rate between 1600 and 1900 per day was considered for a 60-day period. Casualties were distributed among all potential members of the National Disaster Medical System. The system was modelled using SLAM simulation and FORTRAN computer code.

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CASUALTY EVACUATION AND DISTRIBUTION USING B-767 AND C-9 AIRCRAFT

I. CONCEPTUALIZATION

Introduction

A great challenge facing the Military Airlift Command (MAC) is to satisfy the airlift requirements of the Department of Defense (DoD) in the event of a major conventional war in Europe and other regional conflicts at the same time. One important airlift requirement that this research effort investigates is the European evacuation and CONUS distribution of wartime casualties.

In a Congressionally Mandated Mobility Study (CMMS) in 1981, the DoD determined that an airlift capability of 66 million-ton-miles per day (MTM/D) was necessary to support all combat forces (10:53). Today, MAC has about a 35 MTM/D capability; but in referring to the 66 MTM/D goal, General Thomas Ryan, CINCMAC, stated, "... we will attain it before the end of the century" (10:53). Recent airlift additions and modifications are closing the gap.

Enhancements. MAC has made considerable progress toward a 66 MTM/D capability. As reported in the November issue of Air Force Magazine (10:53-89), airlift enhancements include all MAC forces. First, the C-141 "Starlifter" fleet has been modified for aerial refueling and its cargo compartment has been stretched thus increasing its bulk cargo capacity by 30%. The C-5A "Galaxy" is being modified with stronger wings and engines. Also, the first of MAC's newest airlift addition, the C-5B,

will be delivered by December 1985 and the fiftieth should be delivered in 1989. Additionally, full scale development of the C-17 was approved in the summer of 1985. If fully funded, 210 C-17 aircraft will be produced. The C-130 "Hercules" aircraft outer wing boxes are being replaced, extending its flying life up to 40,000 hours. Also, a joint SAC-MAC procurement of 60 KC-10 aircraft will enhance airlift as an in-flight refueler and a cargo plane. Finally, some aircraft of the Civil Reserve Air Fleet (CRAF) are being modified to carry military cargo(10).

Aeromedical CRAF. Airlift augmentation by U.S. owned commercial aircraft will be implemented in stages depending on the severity of any national emergency. The CRAF will transport soldiers and supplies to the war theater and may also be tasked to evacuate military and state department dependents. MAC has considered modifying the Boeing aircraft (B-767) during its production phase to make it aeromedically capable (27). The B-767 would be used primarily for intertheater evacuation, while the C-9 "Nightingale" would be the primary intratheater evacuation aircraft. Smaller CRAF aircraft could also be modified to someday replace the C-9 if they are required for the tactical evacuation of casualties. These modified CRAF would be incorporated into the CRAF plan and used when necessary.

Aeromedical Requirement. The Medical Readiness Division of the Office of the Surgeon General anticipates the saturation of U.S. military hospitals in Europe in the early stages of the conflict. As a result, the DoD plans to evacuate all casualties that cannot be returned to duty within 15 days (17).

Under current plans, the C-141 will be used for the strategic evacuation of these casualties. This will be accomplished during the return (backhaul) portion of its resupply mission. The medical mission could impact the resupply mission but its impact is difficult to estimate. An examination of the extra time required for a C-141 to execute a combined resupply and evacuation mission may be instructive.

Resupply Time. The evacuation impact on the resupply mission will be examined in terms of the difference in turn-around-times for a C-141 mission with and without the evacuation requirement. The planned maximum ground time for cargo onload or offload is two hours and fifteen minutes (23). Concurrent refueling operations and optimal crew staging are assumed for the contingency. Therefore, elapsed turn-around-time should not exceed four and one-half hours plus the enroute flying times for the C-141 resupply mission.

With the medical evacuation tasking, resupply turn-around-time will include the following additional activities and estimated average times to complete each activity (6):

1. Repositioning to casualty onload location - 45 minutes
2. Reconfiguring aircraft for casualties - 45 minutes
3. Uploading casualties at onload location - 90 minutes
4. Offloading casualties at offload location - 90 minutes
5. Reconfiguring aircraft for cargo - 30 minutes

These activities and estimates are based on the 67 litter patient capacity of the C-141 (23). Optimal crew staging is still assumed. The elapsed turn-around-time for the medical mission is five hours longer than that for the resupply mission alone. The possibility of a medical diversion was not considered but a minimum additional one hour delay would be incurred.

In addition to the resupply impact, other concerns should be mentioned. Hospital beds or C-9 aircraft support must be available at the offload location. This is required because the offload location has already been determined by the resupply requirements and cannot be adjusted for patient convenience. Also, the medical equipment (stanchions, litters, etc.) returning to Europe will reduce the amount of primary resupply cargo that can be carried on each aircraft.

The time factor alone is insufficient to determine the impact each medical mission has on the resupply mission. The C-9 scheduling and the reduced amount of primary war supplies carried on C-141 aircraft are factors that must also be considered. The impact will be reduced or eliminated under the proposal studied in this research.

Proposal

This research effort will examine an evacuation and distribution system using B-767 and C-9 aircraft. The B-767 aircraft will be used primarily for the strategic evacuation mission, while the C-9 aircraft will be used for the intratheater evacuation mission in the CONUS; however, any modified aircraft could execute the stateside mission. If the C-9 is deployed to Europe for tactical evacuation of casualties, a replacement aircraft (probably CRAF) would be required.

Research Question

As an alternative to the present evacuation plan, what is the structure of an evacuation and distribution network using Civil Reserve Air Fleet (CRAF) and C-9 aircraft resources and how can its performance be evaluated?

Background

The existing plan and any alternatives addressing the evacuation and distribution of casualties is an intensive routing and scheduling problem. It was originally investigated by Lt. Col. McLain at MAC's Operations Research Division as a multi-commodity network flow problem (20); his Casualty Evacuation Model (CEM) included the following:

1. 9 European onload locations.
2. 73 CONUS offload locations.
3. 95 enroute cargo terminals.
4. 11 patient categories.
5. 60 one-day time periods.

A review of the literature pertaining to this kind of problem will begin with the classical approach to solving network related problems. A very recent study that examined some variations of the original problem will also be reviewed. Finally, the latest study on solving large network problems will be examined.

Past Related Studies. The casualty evacuation and distribution problem, notwithstanding its size, is a classical network problem if the patient categories and the time periods are disregarded. In this case, one attempts to find the shortest path or maximum flow solutions. If the time periods are included, the problem becomes a multi-period transportation or transshipment problem with the objective to minimize shipping costs. Each approach will be examined.

Network problem. The casualty evacuation problem has well-defined sources, sinks and a connected system of arcs on which a commodity flows (31). Documentation for solving the network for maximum flow or shortest path includes that provided by Hillier and Lieberman (15:241) or Wu and Coppins (36).

To maximize flow, the three-step algorithm by Hillier and Lieberman might be used but the route structure must already be established, in which case the problem can be reduced to assigning aircraft to routes (5). Unfortunately, the CEM is not static; the supply and demand at the sources and sinks change daily, and the route structure has not been established. As a result, other techniques will be reviewed.

The four-step algorithm presented by Wu and Coppins can be used to find the shortest paths in the network. A research effort by Guenther involved the distribution of mail to six cities located within 50 miles of each other (13). In addition to finding the shortest path, he showed that exhaustive enumeration (complete identification) of all possible routes would result in an optimal solution. Unfortunately, with larger networks (he tried a 10-node system), the exhaustive enumeration technique became prohibitively expensive. The underlying complication in the CEM is the size of the problem.

Another shortest path approach investigated by Guenther had also been used by Gaskell (12). By using various refining heuristics (a rule-of-thumb for solving some aspect of a problem (7:623)), Guenther avoided the complete enumeration of feasible solutions by early elimination of partial solutions known to produce sub-optimal final solutions. If the CEM is sub-divided into a system of smaller networks, this approach could be used to select a shortest path routing structure for each subsystem. Unfortunately, a more difficult problem arises - what criteria should be used for sub-dividing the network and then, in what sense is optimality defined in the larger system?

Transportation Problem. The CEM is also similar to a special category of network problems called transportation problems. Instead of maximizing flow or minimizing distance, the transportation problem has associated shipping costs for each route between source and sink. The objective is to choose the combination of routes that minimizes total shipping or distribution costs (32:187). Hillier and Lieberman also provide methods for solving transportation problems (15:134).

In separate research on the Non-combatant Evacuation Operation (NEO), Gullett (14) and Moncure (24) observed that the size of the problem prohibited the application of any of the methods presented by Hillier and Lieberman. The NEO deals with the evacuation of military and State Department dependents from Germany in the event of a conflict. A one-day snapshot of the CEM without regard for the patient categories would require a square matrix with 177 rows, or less than 100 rows if the number of intermediate transfer locations could be reduced to less than a dozen (15:150).

The solutions would be one-day estimates of a particular static scenario rather than the actual dynamic evacuation process. This limitation, together with the complexity of solving a multi-commodity flow problem, substantially reduces the applicability of classical network approaches to solving the casualty evacuation problem.

Recent Study. The groundwork for the Casualty Evacuation Model (CEM) was accomplished by Lt. Col. McLain, Deputy Chief of the Operations Research Division, MAC Headquarters. In March 1985, Alfano and O'Neill completed their study of a modified CEM (1). They assumed that all casualties would arrive at a centrally located eastcoast

military base. From that location, CRAF aircraft would transport patients to two other distribution centers in the CONUS. C-9 aircraft would distribute up to 40 patients (35:156) to the various hospitals from one of the three distribution centers. An average of 1000 casualties per day was used in their model.

The hub-and-spoke model developed by them was tested in three phases. The first allowed an unlimited number of C-9 aircraft. It required up to 17 C-9s and the average patient spent 3.3 hours in the network. The second phase limited the number of C-9s in each distribution area to achieve the same average patient time. The model required at least 7 aircraft per distribution center. The last phase allowed patients to queue at the distribution centers in order to fill each C-9. This version required 16 C-9 aircraft (1:78).

The final conclusion from Alfano and O'Neill's study was that an alternate distribution system should be developed to reduce the C-9 requirement. The reason for this - the Air Force has only 11 CONUS based C-9 aircraft (1:75).

Current Status. Optimality in terms of either the shortest path or maximum flow for a network of this size has never been achieved due to the problem's combinatorial nature and thus, "beyond the scope of existing computer codes" (20). However, continued interest in this problem has prompted the Operations Research Department of Southern Methodist University (SMU) to submit a proposal to the Air Force Office of Scientific Research for a grant to develop and evaluate a casualty evacuation model for a European conflict (17). The grant was made and the study should begin in December 1985; however, preliminary results

of a smaller version of the original problem were presented by Dr. Allen of the SMU staff (2).

Dr. Allen's constraint matrix of McLain's original version had more than 137,000 rows. To solve this problem, Dr. Allen planned to develop a specialized procedure to solve a scaled down version of the original problem. Time periods, patient categories and facility locations could be aggregated to reduce the size of the problem.

A procedure was developed to solve a test problem of about 9000 rows. It involved generating upper bounds on the objective function by solving the problem using a resource-directive decomposition technique (15:704), and then generating lower bounds on the objective function by partially solving a dual of the problem (2:8). The iterative processs stops when the difference between both bounds reaches a certain tolerance. The computer program "EVAC" developed by Allen required less memory and about 65% less time than the program "MCNF" developed by Kennington to solve a similar problem (2:48). The differences were due to Kennington's program seeking an exact optimum. "EVAC" should be a good model for the scaled down casualty evacuation problem.

The SMU Operations Research staff have also proposed to investigate the applicability of using the projective algorithm of Dr. Narendra Karmarkar of AT&T Bell Labs to solve the full model (17). A test case using an SMU version of Karmarkar's algorithm to solve assignment problems was not encouraging; however, the poor result may be due, in part, to an inaccurate version or application of the algorithm (3).

Review Conclusion. Many problems of this type have been solved by various methods; however, none of the problems approached the size of the CEM. Optimality, though desirable, is not the goal of this study. A feasible solution will be found and evaluated to provide a basis for comparison and futher study in this area. The methodology used by Gullet, Moncure and Alfano will also be used in this research effort - simulation - to be discussed in Chapter II.

Tactical Preparation

According to the DoD Theater Combat Medical System (Figure 1), casualties will be processed through four echelons of medical care before reaching their recovery hospital.

	First Echelon	Second Echelon	Third Echelon	Fourth Echelon
USAF	Self Aid/ Buddy Care	AF Aid Station	250/500 Bed Hospital	500 Bed Hospital
NAVY	Navy Corpsman		Hospital Ship	COMMZ Hospital
USMC	Navy Corpsman	Battalion Aid Station	Medical or Hospital Co. or Hospital Ship	COMMZ Hospital
ARMY	Medical Aid Man or Battalion Aid Station	Medical Co. or HQ and Support Co.	Combat Support Hospital or MASH	General Hospital

Figure 1. DoD Theater Combat Medical System

The first echelon is self-aid or buddy-care in the field. At the second echelon, wounds and the general conditions of each patient will be evaluated to determine the priority for further treatment and

evacuation. The third echelon is the first medical facility staffed and equipped to provide specialty care. General surgery and further evacuation determinations will be performed here. Comprehensive medical care will be provided at the fourth echelon in theater if the patient can be rehabilitated within 15 days. If not, evacuation to the CONUS will be coordinated through the Armed Services Medical Regulating Office (ASMRO) and the Joint Medical Regulating Office (8).

National Disaster Medical System

In December 1981, President Reagan established the Emergency Mobilization Preparedness Board to develop national policy and programs to improve emergency preparedness. A National Disaster Medical System (NDMS) was developed in response to the President's mandate. The NDMS task force includes the Department of Defense, Department of Health and Human Services, the Federal Emergency Management Agency and the Veterans Administration (29).

The NDMS is designed to care for the casualties of any incident that exceeds the medical care capability of an affected region. Two often quoted situations for which NDMS was designed include a major California earthquake and a conventional European war. NDMS will inclde all major metropolitan areas of the nation (26). It incorporates the Civilian-Military Contingency Hospital System (CMCHS) that already includes 770 hospitals in 48 metropolitan areas (29). The additional proposed metropolitan areas are shown in Figure 2.

MAC Mission

The Military Airlift Command will provide the airlift resources to connect the operations of the DoD Theater Combat Medical System and the National Disaster Medical System.

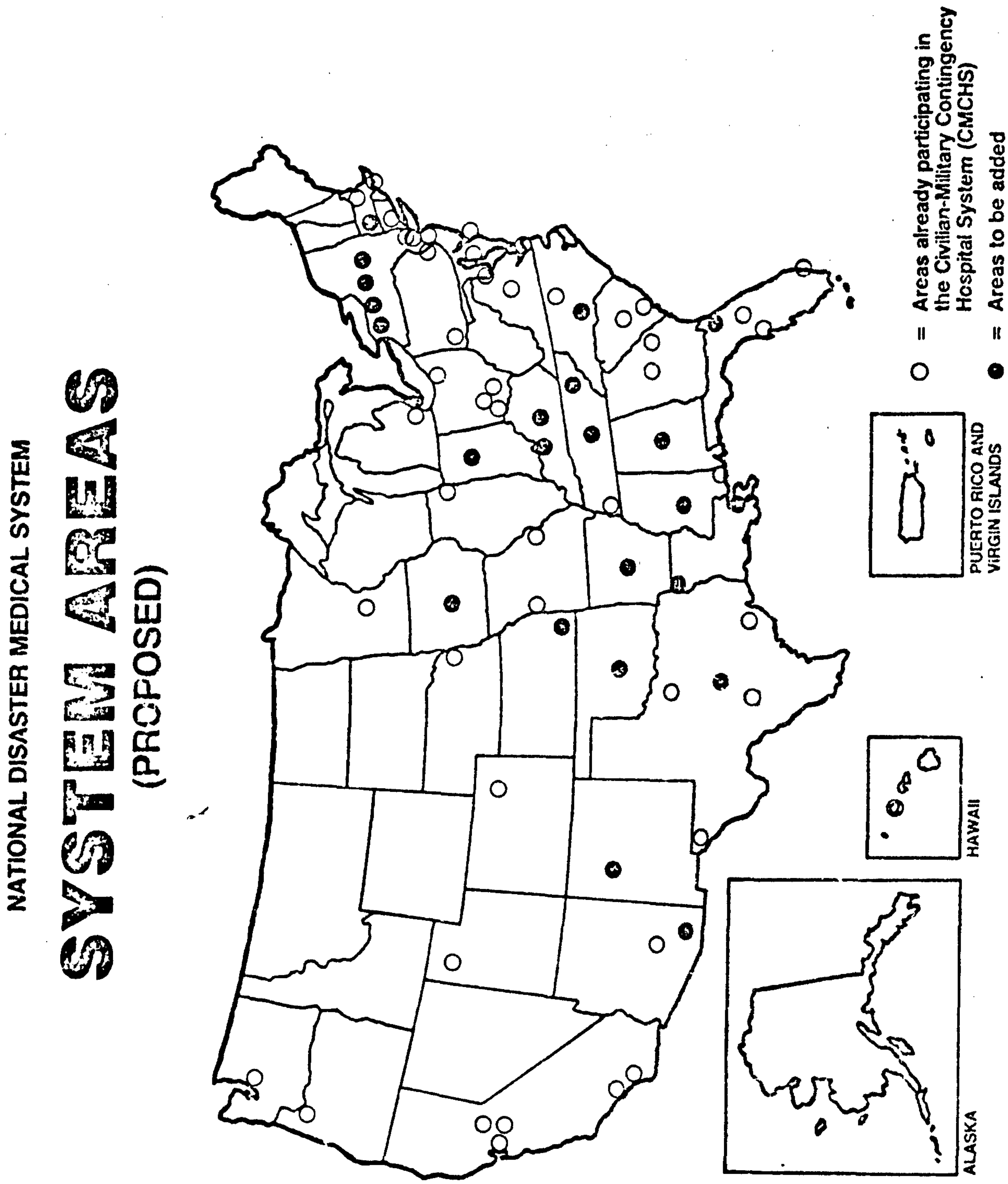

Figure 2. National Disaster Medical System Areas

Research Limits

This research effort will examine one evacuation and distribution concept starting with the patient's release from the European fourth echelon of care to his arrival at one of 94 U.S. metropolitan area airports (9). The operation of the evacuation and distribution system will extend through the first 60 days of the conflict. The estimated number of casualties will vary between 1000 and 2500 per day. Other parameters of the model will be discussed later.

Measures of Effectiveness

In an operational environment involving expensive and limited resources, reasonable measures of mission effectiveness include aircraft and crew utilization, average cargo capacity utilization, and the average time required to transport a given tonnage to a specific location (closure time). From a medical perspective, these measures would be superceded by the patient's average time in the system, expected environmental conditions and the maximum time any patient might spend in the evacuation and distribution system.

To varying degrees, all these measures will be considered in the proposed model of the system. The primary measure of effectiveness will be the average time a patient spends in the system (response variable). This time will begin when a full load of patients is released for evacuation and will end when those patients arrive at their final destination airport.

It is important to note that a large average time in the system does not mean that a patient spends that much time travelling in an aircraft or bus. The response variable (time in the system) includes that time spent in the hospital waiting for transportation.

Secondary measures of effectiveness include resource utilization rates, maximum time in the system, and the number of patients awaiting evacuation. Also, since all CRAF aircraft will depart with a full load of casualties, maximum cargo utilization rate will be achieved.

Research Objective

A routing network between a casualty onload location, intermediate locations, and an aggregation of 75 final offload locations will be designed and evaluated under various conditions. These conditions include relatively high and low values of the major factors affecting the primary measure of effectiveness. The factors include daily casualty rate, CRAF capacity, ground times, flying time, number of CRAF aircraft and number of C-9 aircraft.

Sub-Objectives. Primary sub-objectives include determining how many intermediate locations will be required and where they should be located. Aircraft patient capacity and average daily casualty rate will be determined in order to estimate the average number of loads departing Europe. From this, an estimate of the required number of CRAF aircraft can be made. With the simulation model of the network, aircraft utilization rates will be determined.

Summary

Airlift plays a vital role in the conduct of all contingency operations. Potential airlift shortages during a conventional European conflict could have disastrous consequences. The recent force modifications, planned additions and contingency augmentation plans may not be sufficient to meet all the DoD wartime demands, including casualty evacuation.

The usual techniques for solving network problems are not appropriate for the CEM because of its large size. In a review of related studies, this limitation was recognized. Simulation techniques used by Alfano and O'Neill seem to be the most appropriate method for addressing this problem and will be discussed in Chapter II.

This study will examine an alternative evacuation and distribution plan based solely on CRAF and C-9 resources. It will begin with the patient's release in the European fourth echelon of care and end with his arrival at the airport nearest a NDMS participating hospital. The primary measure of effectiveness will be the patient's time in the system, controlled by the six major factors included in the network. This performance measure will be used to evaluate the network at different factor levels. The study will attempt to develop an evacuation and distribution network that results in acceptable measures of performance including the average and maximum time in the system, and resource utilization.

II. MODEL FORMULATION

Introduction

The casualty evacuation and distribution problem is a complex interaction of medical requirements, aircraft and aircrew scheduling and support operations. It is a dynamic problem that has optimal or near-optimal solutions for each situation or significant time period in question. The focus of this research effort, however, is on designing a simulation model of an evacuation and distribution network and evaluating the model's performance.

Simulation

The techniques of simulation are well suited for this type of problem. Banks and Carson define simulation as "the imitation of the operation of a real-world process or system over time" (4:2). Simulation is a method a research analyst can use to evaluate, predict and sometimes, optimize the operation of a system that can not be formulated analytically (33:20). With the flexibility provided by simulation, one can experiment with the system to determine how it reacts to changes before committing resources.

For these reasons and others, Alfano and O'Neill employed simulation techniques to evaluate their proposed evacuation and distribution system (1:20). They simulated the system for 60 days beginning with the arrival of 1000 patients per day at an eastcoast location via C-141 aircraft.

Using CRAF and C-9 aircraft in a hub-and-spoke system, the model simulated the distribution of casualties among 73 locations. It

measured average and maximum time in the system as well as resource utilization. The system required approximately 10 CRAF aircraft and between 14 and 17 C-9 aircraft. The average time in the system was under three and one-half hours.

Because of the difference between the present CONUS-based Air Force C-9 inventory and the number required by the simulation, they recommended alternate systems be developed. One of these included the exclusive use of CRAF and C-9 aircraft for evacuation, the basis of this research study.

Two other research efforts employed simulation techniques to model a complex evacuation problem. Moncure and White (24) and Gullett and Stiver (14) investigated the Non-combatant Evacuation Operation (NEO) for the Federal Republic of Germany in case of a major conflict.

The NEO plan entails the evacuation of approximately 750,000 military dependents, state department employees, and others from West Germany. The studies converted all CRAF and C-5 aircraft to C-141 equivalent aircraft. Then, for various capacities and aircraft availabilities, the models provided evacuation times that were compared to area "overrun" times under different scenarios. Both research efforts used Q-Gert simulation techniques to model the system.

As in the previous studies, discrete event simulation techniques will be used in this study to model the network. The state of the system changes only with the occurrence of specific events. Some of these events include the release of patients from hospitals in Europe, their arrival in the U.S. and their discharge from the recovery hospital. Each significant event and intervening activity duration will

be simulated in the model using Simulation Language for Alternative Modeling (SLAM) by Pritsker (30:2).

Scenario

The strategic evacuation and CONUS distribution of casualties resulting from a conventional war in Europe will be simulated for 60 days. This is the same time period used by Alfano and O'Neill and by the Armed Services Medical Readiness Office for medical planning and force requirements (8). The scenario assumes that by the sixtieth day, sea lines of resupply will have been established thus reducing the airlift requirement. These airlift resources could then be used for evacuation.

During the first 60-day period, this study assumes that C-141 aircraft will not be used for casualty evacuation. CRAF aircraft, primarily B-767, will evacuate the casualties and augment the C-9 aircraft in the distribution phase. If the C-9 aircraft are deployed, other modified CRAF or more B-767 aircraft would be required.

Network Structure

Onload. The original Casualty Evacuation Model (CEM) had nine onload locations throughout Europe. In this study, these locations have been reduced to one centrally located point. The primary measure of effectiveness (average time in the system) is not affected by this simplification because the patient's time does not start until a full load of patients is released for evacuation. The simplification eliminates the need to specify the nine onload points and the proportion of total casualties departing from each onload point.

__Enroute Time__. The corresponding flying times from nine locations has also been eliminated. Samples from one of four uniform distributions with parameters based on average minimum and maximum flying times to each of four U.S. staging bases will represent the flying times for each transatlantic mission.

__Enroute Stage__. Replacing the original 74 intermediate locations of the original model (20) are the four staging bases - Boston, New York, Philadelphia and Washington. In the original CEM, every likely enroute stop was included because of the many cargo onload locations and numerous routings. Because the CRAF mission is exclusively a medical mission in this study, these enroute locations are not required.

The specific staging bases were selected primarily due to the large number of hospitals nearby. They are also within the B-767 fuel range. Each location presently supports international flights and is a major operations center for many commercial carriers. Activation of the CRAF plan and the medical tasking would impose minimal ground support changes to the existing structure.

__C-9 Operations__. Interface between the B-767 and C-9 aircraft will occur only in Washington. The C-9 distribution network includes all hospitals located within about two hours flying time (approximately 900 miles) from Washington except those hospitals served by the other three staging bases. The semi-circle in Figure 3 roughly outlines the C-9 distribution area.

__B-767 Operations__. Boston, New York and Philadelphia will serve hospitals located within approximately 2 hours driving time (about 100 miles). Figure 3 identifies the areas in the western U.S. served by

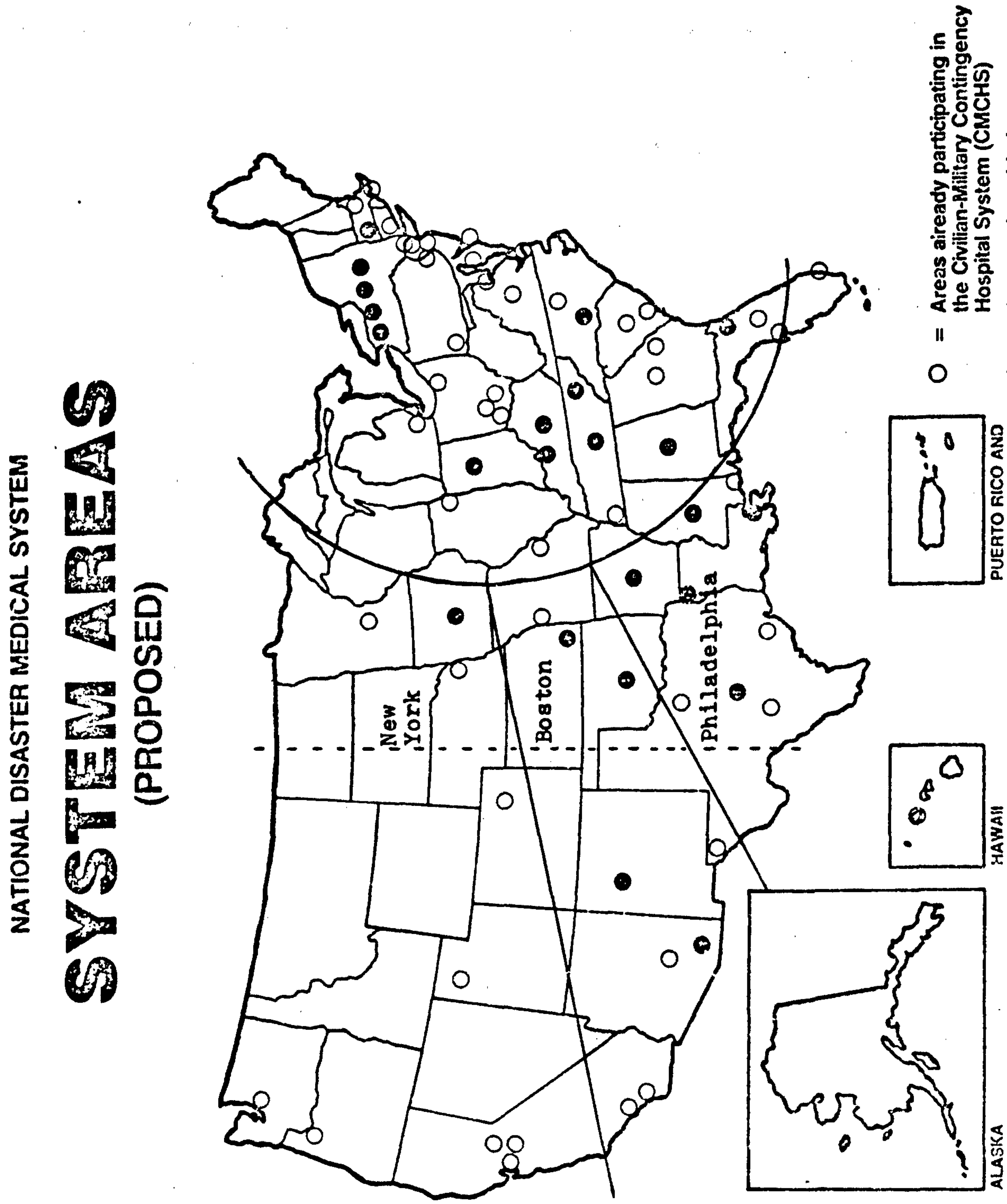

Figure 3. Stage Base Service Areas

each staging base. The dashed line indicates the extent of B-767 operations required for this model.

Data File. An array of cities served by each staging base is ordered according to its distance from the stage location. The array data includes the flying time and number of available hospital beds for each city. The data is part of the initialization subroutine of the fortran computer code shown in Appendix A.

Cities can be added or deleted from the network with only minor changes to the code, but the ordered sequence based on distance must be maintained. This will ensure that the closest cities with sufficient empty beds are selected first for each staging base by the fortran subroutine "SERCH".

CRAF Destination. The proportion of B-767 missions destined to each staging base was determined from the total number of beds served by that base and the number of beds within two hours driving time. The requirement was that each area be filled at approximately the same rate.

Half of all CRAF missions are scheduled to Washington; the other half are divided among the other three cities. This avoids saturation of ground facilities and provides some separation between arriving flights. Every other B-767 from Europe is directed to Washington by the "SELECT" node in the SLAM network code.

When an aircraft arrives at Boston, New York or Philadelphia and the number of empty beds in the immediate area is equal to or greater the capacity of the B-767, all patients are offloaded and the B-767 is returned to Europe. Otherwise, the mission continues to the first city

served by the staging base with enough empty beds for all patients aboard. The patients are offloaded and the aircraft is returned to the staging base and then to Europe.

When an aircraft arrives at Washington, all casualties are offloaded and the CRAF is returned to Europe. For each 40 patients offloaded (C-9 capacity), two conditions are checked. For the first condition, a subroutine searches an array for the nearest city with at least 40 available beds. The second condition requires at least one C-9 be available. If both conditions are met, the patients are flown to the selected city.

Patient Overflow. For all flights to the U.S., an overflow condition can develop when one of the following situations occurs:

1. If no beds are available in Boston, New York or Philadelphia area hospitals or their respective service areas, or

2. If no C-9 aircraft are available at Washington and no beds are available in Washington area hospitals, or

3. If no beds are available in the C-9 servicing area or in the Washington area hospitals, or

4. If less than 30 patients remain at Washington after full C-9 loads have departed and no beds are available in Washington area hospitals.

In these cases, all patients are offloaded, admitted to area hospitals and assigned to beds that were not previously contracted for use through the National Disaster Medical System (NMDS). Recall that 25% of the beds in each participating hospital are contracted. If the overflow patients require an additional 10% of a hospital's capability (total 35%), then the selected combination of input parameters is unacceptable and will be rejected as a viable option.

The model maintains statistics on the number of patients causing an overflow conditions and where it occurs. In testing the model at high casualty rates, overflow occurred at Washington but the number of casualties causing this condition was less than the limits shown in Table I based on the 35% restriction above.

Table I

Hospital Overflow Data

Stage Location	Contracted Beds	Overflow
Washington	4360	1740
New York	13420	5360
Boston	4410	1760
Philadelphia	4390	1750

Patient Categories

The Armed Services Medical Readiness Office has classified all combat casualties into 309 categories (8). The Military Airlift Command has aggregated these categories into the classifications shown in Table II (1:23). The estimated percentage of total casualties in each category and the expected number of days in recovery is included. In case the recovery periods have been underestimated, a 25% increase in the recovery period will be tested during the model experimentation phase. The results will be included in chapter IV.

These patient categories have been reduced based on their length of stay in the recovery hospital for this study. It assumes that every hospital can admit any category patient; however, some casualty screening process could be implemented for certain cases. The revised categories are shown in Table III.

Assuming every hospital can admit any patient eliminates the need to match a patient with a particualar type hospital bed. The model determines discharge dates based on patient category and the arrival date.

Table II

Patient Characteristics

Category	% of Total	Recovery Period
1. Medical	20	16
2. Psychiatric	7	29
3. General Surgery	31	24
4. Orthopedic Surgery	19	50
5. Neurosurgery	6	36
6. Oral/Maxillo Facial	7	40
7. Urology	1	12
8. Opthamology	3	27
9. Burns	2	33
10. Thoracic Surgery	4	54
11. Spinal Cord	<< 1	38

Table III

Revised Patient Characteristics

New Category	Old Category	Percent	Recovery Period
I	1, 7	21	16
II	2, 3, 8	41	25
III	5, 6, 9, 11	15	38
IV	4, 10	23	51

Assumptions and Limitations

Assumptions and limitations are necessary to simplify the model and reduce the number of computations. Some apply to the structure of the model while others refer to the data. While some have already been mentioned and others have not yet been discussed, all assumptions and limitations will be listed here for easier reference.

Tactical medical evacuation operations are presumed functioning properly; therefore, CRAF aircraft will not be subject to the hazards of flying near hostile areas.

Maintenance. Mechanical delays and diversions are not modelled in the simulation; however, additional ground time is scheduled for each eastbound CRAF at the stage location. An adjustment in the number of aircraft required by the model will be proposed in the next chapter to account for the absence of maintenance factors. An increase in the number of B-767 aircraft in tho system will offset the increase in the patient's average time in the system caused by maintenance delays and diversions.

For the C-9 aircraft, no more than nine are used in the model even though the Air Force has 11 located in the U.S. The extra aircraft can be used for maintenance spares or for special medical missions not included in this study.

Weather. Delays and diversions caused by weather have not been incorporated into the model. These deviations would have to be frequent and extensive to make a statistically significant difference in the patient's average time in the system. A modification similar to the maintence adjustment will be proposed to allow for this factor.

Aircraft Utilization. The model requires that all B-767 aircraft be fully loaded before take-off. This maximizes aircraft capacity utilization without affecting the primary measure of system performance or causing any additional delay of patients already waiting for transportation. Also, continuation flights for B-767 aircraft arriving

at Boston, New York or Philadelphia, will be made only to destination cities that can admit a full load of patients for maximum aircraft efficiency.

The model does allow the C-9 to depart with 75% of its normal capacity in order to reduce the number of overflow patients at Washington area hospitals. Thus, if 110 casualties arrive on one B-767, 30 patients would remain after two full C-9 loads have departed. These patients would fill Washington area hospitals within 20 days if eight aircraft arrived each day. If 130 casualties arrive on each B-767, only 10 patients would remain after three full C-9 loads have departed. For the same arrival rate as above, Washington area hospitals would not be filled within 60 days.

Ground Support. Ground transportation required to move patients between hospitals and aircraft or between aircraft is assumed available. This includes vehicles for the trips to hospitals within approximately 100 miles of any offload location.

CRAF Capacity. The passenger capacity of a B-767 is about 220 (34); however, a litter patient occupies about two and one-half times more space than an ambulatory patient. The expected number of litter patients varies from 60% to 90% of the total number of casualties. This reduces the patient capacity to between 100 and 140 for the CRAF. These factor levels will be discussed in the next chapter.

Casualties. Estimates of the number of casualties per day are classified; however, Alfano and O'Neill's study and other unclassified estimates have used 1000 or more per day (8). To model a variable casualty rate, a triangular distribution with a low parameter value of

1000 and a high parameter value of 2500 will be used to provide a reasonably wide range of casualty rates. The triangular distribution was selected because of its simplicity. Also, it does not have the problem associated with extreme values found in the tails of other distributions. The effect of various modal values will be examined in the next chapter.

Hospitals. All hospitals located within two hours driving time (about 100 miles) from each offload location have been aggregated in the array of cities for each staging base.

Computer Time. To save computer processing time, the model will generate one entity for every ten casualties. Hospital bed availability and aircraft capacities have been appropriately reduced. Thus, the capacity of a C-9 will be 4 instead of 40 and a B-767 aircraft capacity will range from 10 to 14.

Verification

Model verification is an inherent part of model development from its conceptualization through summary data analysis. Verification ensures that the conceptual model is accurately reflected in the SLAM and fortran computer code (4:379). One other result of verification is increased confidence in the model.

The following verification techniques were carried out:

1. Logic verification - the computer code was critiqued by my thesis advisor for logic and programming methods.

2. Flow diagram - entities created in the network were traced through the system. Every possible path terminated at a data collection point so no entity can be trapped in the network.

3. Documentation - the main program and each module of the computer code include a general description of its purpose. Each new variable is defined.

4. Sensitivity testing - each parameter, in turn, was varied while all others were fixed to verify that the behavior of the model was as expected. The concern here was to verify that the response variable increased or decreased when it should without regard for the amount of increase or decrease.

5. Stress testing - each parameter was independently tested at high and low values to cause the model to "blow-up" or stabilize as expected.

Validation

No model is ever totally representative of the system (4:384), but the ultimate test of its validity is its ability to predict the future behavior of the real-world system. For the scenario simulated in this study, it will hopefully never happen; however, other validating techniques are available to increase the modeler's confidence that the model is accurate. The following techniques were applied:

1. Face validity - the model appears reasonable. It behaves as expected when input variables are changed. A high degree of realism is built into the model through reasonable assumptions regarding the network structure and reliable data.

2. Structural assumptions - the model's simplifications and abstractions of the evacuation process appear reasonable based on my prior experience in strategic and tactical airlift operations.

3. Sensitivity analysis - the model provides reasonable data when input parameters are varied. Unlike sensitivity testing for verification, sensitivity analysis is concerned with the amount or degree of change in the response variable.

Summary

Simulation techniques are ideally suited to evaluate the performance of an evacuation and distribution network. Fortran computer code and Simulation Language for Alternative Modeling (SLAM) will be combined in a network-discrete event simulation to model the evacuation and distribution of casualties resulting from a 60-day conventional conflict in Europe.

The structure of the network includes one onload location, four staging bases and a total of 49 offload points with a combined total of 83180 available hospital beds in 87 cities. Each staging base serves cities listed in an array based on shortest distance first and includes the flying time to each city and the number of beds available in its hospitals.

The original 309 categories of patients has been reduced to four categories based on their recovery times. Also, B-767 aircraft will be fully loaded for every flight; no aircraft will proceed to destinations with insufficient beds for the entire load.

All major assumptions and limitations to reduce the complexity of the model and computations required have been included. These refer to both structural and data assumptions, some of which will be further explained in the experimental design of the model in the next chapter.

III. EXPERIMENTAL DESIGN

Introduction

The Casualty Evacuation Model (CEM) developed in chapter II simulates a system composed of factors that affect a patient's average time in the evacuation network. This chapter will develop an experimental design as described by Montgomery (25) using analysis of variance (ANOVA) techniques (16) to quantify the statistical significance of the factors and their interactions.

The purpose of the ANOVA is to compare the different systems specified by the experimental design and determine any factors or interactions that can be eliminated from the model or fixed at some arbitrary, but reasonable, levels. A factor may have no statistical or practical significance in the model if a change in the level of the factor causes no appreciable change in the response variable (average time in the system), when all other factors are held constant.

After the significant factors and interactions have been determined, multiple regression techniques will be used to develop a response surface equation. This will be addressed separately in Chapter IV. The equation can be used to predict the value of the patient's time in the system given any combination of factor settings within a specified range.

The experimental design development begins with data collection and includes a factor screening process. Specific levels of each factor will be established and coded depending on the experimental design

selected. Other areas, including variance reduction techniques will be addressed.

Data Collection

Chapter II included data for the casualty rate distribution and hospitals that will be used in the simulation model. This data, as well as other factor data, will be included in this section.

Hospital Locations. The MAC Operations Research Division provided a list of 74 metropolitan areas and the total number of beds in each area as of mid-1985 (9) shown in Appendix B. The locations were aggregated into approximately 40 areas that will be served by the staging bases outlined in chapter II.

Committed Beds. The list above included over 400,000 available beds; however, only about 25% of these beds can be committed for use by the military (27). This provides 100,000 beds but only 85,000 beds located in the eastern half of the country are necessary for this study.

Casualty Rate. As stated in chapter II, a triangular distribution with low and high parameter values of 1000 and 2500 respectively, will be used to provide a wide range of casualty rates. By changing the modal value of the distribution, the expected value can be increased or decreased as necessary. Specific values of the mode will be discussed in a later section.

CRAF Capacity. Also from chapter II, the passenger capacity for a B-767 aircraft is about 220; but the space required for a litter patient is about two and one-half times that required for an ambulatory patient. Estimates of the number of litter patients vary from 60% to 90% of the

total casualties. These percentages correspond to aircraft patient capacities between 100 and 140 based on the 220 passenger capacity of the aircraft. These values represent high and low limits; however, other capacities will be evaluated.

Number of B-767. This factor is very dependent on the casualty rate and the capacity of the aircraft. Using reasonable low and high values for the casualty rate and an average 120 patient capacity, the expected number of aircraft required is between 14 and 16. Based on initial pilot runs of the simulation model, higher values were required. This will also be addressed in a later section.

Number of C-9. Because the Air Force only has 11 C-9 aircraft stationed in the CONUS (10), this will be the maximum number available. However, the model will be exercised at lower values to determine the effect this has on the response variable.

Transatlantic Flying Time. Transatlantic crossing times vary with the route selected, altitude and time of year. Banks and Carson recommend using a Uniform distribution when very little is known about the actual distribution or when the events are truly random (4). The parameters for the distributions will be the average minimum and average maximum flying times based on the aircraft's cruise speed and average wind factors.

The distribution data for the transatlantic flights to the four arrival or staging bases is shown in Table IV. The return flight to Europe has a Uniform distribution also shown in Table IV.

__CONUS Flying Time.__ The flying times for all CONUS flights are based on the distance between airports, aircraft speed and wind factor; but the effect of short distances, where the aircraft never attains its design cruise speed, is also incorporated. This data is stored in the array of cities served by each staging base shown in Appendix A.

Table IV

B-767 Flying Time Distributions

Destination	Flying Time
Boston	Unfrm(7.7, 8.7)
New York	Unfrm(8.0, 9.0)
Philadelphia	Unfrm(8.2, 9.2)
Washington	Unfrm(8.5, 9.5)
Europe	Unfrm(7.0, 8.5)

__Ground Time.__ Normal ground time for onload, offload and refueling during contingency operations is two and one-half hours for C-141 aeromedical missions. No guidelines are available for missions with as many as, say 120 patients, but reasonable estimates can be made using the normal C-141 time assuming a full load of 67 patients. The average time per patient is about two minutes and 15 seconds. For the B-767 with 120 patients aboard (75% litter), this rate would require 3.375 hours. C-9 ground time can be determined similarly.

Assuming all ground operations can be conducted concurrently with onloading or offloading, the data in Table V will be used in the simulation model. Additional time is provided for eastbound CRAF at staging locations for minor maintenance. Purpose codes are:

on = onload
off = offload
cc = crew change
ref = refueling
mx = maintenance

Table V

B-767 and C-9 Ground Times (Hours)

Aircraft	Departure	Time	Purpose
CRAF	Europe	3.5	On, ref, cc.
"	West Stage	1.5	Ref, cc.
"	East Stage	4.0	Off, ref, cc, mx.
"	Other points	3.0	Off, ref.
C-9	Washington	2.5	On, ref, cc.
"	Other points	2.0	Off, ref.

Initial Screening

All factors discussed above are important aspects of the real-world system simulated in the model; however, one or more of them may not be significant in terms of changes in the response variable. Other factors directly affect the patient's time in the system, but are generally beyond our control or should remain at fixed levels. The specific factors in these case are the flying time and ground time.

For the experimental design, the flying time and ground time factors will not be evaluated at high or low values to examine their effects on the response variable. The CONUS flying time will remain constant while the transatlantic times will be selected from the listed distributions.

The ground times will also remain fixed in order to allow an orderly completion of all ground activities in the proper sequence. While shorter ground times reduce a patient's time in the system, the intense activities required by maintenance, aircrews, medcrews, aerial port teams and command post controllers to attain shorter ground times could not be sustained for a very long time.

By including flying time and ground time as fixed factors within the simulation model, four factors remain in the experimental design. High and low values of each factor will be specified next.

Factor Levels

Casualty Rate. A wide range of daily casualty rates is guaranteed by the choice of the high and low parameter values of the distribution. By setting the modal value at relatively high or low values, the expected values will be high or low accordingly. For the experimental design, a modal value of 1300 will result in an expected value of 1600 casualties per day. A modal value of 2200 will cause the expected value to reach 1900 per day. In both cases, a sample from the distribution can still have very high or very low values, depending on the random number selected.

CRAF Capacity. As stated earlier, the proportion of litter patients among all casualties ranges from 60% to 90%. The MAC Surgeon General's Office has used a patient capacity of about 120 for some medical planning studies (27). This suggests that a 75% litter rate and a B-767 passenger capacity of 220 seem reasonable. So, to determine if the capacity of the aircraft affects the response variable or if interactions are significant, the experimental design will be conducted with aircraft capacities of 110 and 130.

Number of B-767. Based on pilot runs of the simulation model, a reasonable range of the number of aircraft to be considered in the design was from 16 to 18. The original range of 14 to 16 resulted in high response variable values caused by too few aircraft and too many patients waiting for transportation.

Number of C-9. The design will examine the effects of using only six or nine C-9 aircraft. This will also provide an indication of how many aircraft would be required to replace the C-9's should they be deployed to Europe.

Final Design

A full factorial design will be developed to quantify the main effects of each factor and the interactions between factors. Based on the pilot runs of the model and the initial screening process, the low and high levels of each factor have been determined and are summarized in Table VI.

Table VI

Experimental Design Factor Settings

Factor	Low Level	High Level
Average casualty rate	1600	1900
Number of CRAF	16	18
Capacity of CRAF	110	130
Number of C-9	6	9

Non-Constant Variance

The model simulates a potential queueing situation under certain treatment settings. In such cases, the response variable will be significantly autocorrelated (16:438). The reason is clear: the time in the system for an arriving patient depends on the time in the system for a patients arriving ahead of him. The model queue discipline is a first-in first-out process.

The detrimental effects of autocorrelated data can be reduced by appropriate data transformations as suggested by Draper and Smith (11)

and Montgomery (25). A well-known transformation and the one used in this model is the natural logarithm transformation of the response variable. The resulting model is an exponential model in the original response variable. The logarithm of the random errors have a Normal distribution as a result of the transformation.

Variance Reduction

One simple variance reduction technique is blocking on common random number streams (4:458). Each distribution in the model will use a unique random number generator provided by SLAM. As a result, observed differences between means will be due to actual differences rather than due to the variance associated with the distributions.

Variance reduction can also be achieved by use of antithetic variates by inducing negative correlation in the response data (30:506). Unfortunately, two simulation runs are required to produce a single observation. Also, Law and Kelton do not recommend mixing the common random number stream technique with the antithetic variate technique, since cross covariances might actually increase the variance (18). As a result, antithetic variates will not be used in this simulation study.

Sample Size

Montgomery provides a procedure for estimating main effects and interactions when only a single replicate of each treatment can be made (25:273). The method assumes that certain high-order interactions are negligible and may be combined to estimate the experimental error. Because there are only 16 treatment combinations in this design, two replicates were made for each treatment in order to obtain a more accurate estimate of the experimental error.

Analysis of Variance

Because only two levels of each factor are evaluated, the response variable is assumed to be linear over the range of the factor levels selected. However, the response variable for the experimental design is the logarithm of the simulation response value; therefore the logarithm of the response variable is assumed to be linear. It may be inaccurate in describing what is essentially a queueing process, but it will be sufficiently close in order to determine significant factors and interactions.

Contrast Constants. The tables of experimental design algebraic sign for calculating the factorial effects for the 3-factor and 4-factor models can be found in Montgomery (25:268,277). A statistical package (BMDP) was used with these contrast constants and the transformed response variables to determine the factorial effects.

The four-factor analysis of variance table is shown in Appendix C. Significant factors and interactions are clearly evident from the F-statistic. The number of C-9 aircraft and all interactions involving that factor are statistically insignificant in terms of changes in the response variable. As a result, the number of C-9 aircraft in the simulation model will be arbitrarily fixed at the higher value.

An analysis of variance was conducted on the three remaining factors with an extra replicate included and is also show in Appendix C. All interactions remain significant. The results of the experimental design can be used to develop a response surface equation to be discussed in the next chapter.

Summary

Experimental design techniques enable a modeler to determine those factors and interactions that are statistically significant by comparing the changes in the response variable. Following the data collection and model development phases, the evacuation model included six important factors that affect a patient's average time in the system.

An initial screening of these factors resulted in setting the flying time and ground time factors at specified distributions or constant values. Specific levels were selected for the remaing four factors in the final experimental design.

An analysis of variance was performed on the transformed response variable and the contrast constants resulting in the elimination of another factor from the design. All three remaining factors - casualty rate, number of CRAF and CRAF capacity - and their interactions were statistically significant. The response surface equation that can be developed will be discussed in Chapter IV.

IV. RESPONSE SURFACES

Introduction

The experimental design procedures in chapter III indicated three significant variables that will be used to determine the patient's mean time in the system (TIS) for the evacuation structure in this study. This chapter will use those three variables - mean casualty rate, number of aircraft, and aircraft capacity - and the statistical technique called response surface methodology (RSM) to develop an equation that will predict the mean TIS value (28:62).

For the casualty evacuation model (CEM), a response surface equation is valuable because it eliminates the need to conduct additional simulation experiments in order to determine the patient's mean TIS for any values of the three variables within established bounds. This saves time and enables an analyst or project officer to examine the results of many combinations of casualty rates, number of aircraft and aircraft capacities to determine acceptable options based on a subjective or limiting criterion value of the mean TIS.

The process of generating a response surface involves finding a suitable approximation for the true functional relationship between the response variable and the independent predictor variables (25:445). The functional form of the approximating polynomial and the estimation of its parameters will be discussed in this chapter.

Functional Form

Because of the transformation to reduce the effects of nonconstant variance described in Chapter III, the form of the functional

relationship is exponential in the original response variable; however, the functional form of the exponent must be determined. After the original predictor variables are coded as in Chapter III, a linear model will be examined.

Linear Models

The simplest functional form of the polynomial exponent is the linear model. If the predictive accuracy of this form is acceptable to the analyst, the exponential model with linear exponent can quickly and easily provide useful estimates the the mean TIS for the evacuation system. If greater precision is required, a quadratic model will be developed.

Coded Variables. Each independent variable can be recoded in the same manner used in the experimental design techniques in chapter III. These are the familiar contrast coefficients coded from the low and high values of each factor affecting the response variable value. Table VII includes the coded variable values and the transformed response variable that will be used in developing the response surface equation.

Table VII

Data For A First Order Model

Mean Casualty Rate	Number of Acft	Aircraft Capacity	Coded Values X	Y	Z	Response ln W
1600	16	110	-1	-1	-1	2.894
1600	16	130	-1	-1	1	2.673
1600	18	110	-1	1	-1	2.635
1600	18	130	-1	1	1	2.667
1700	16	110	1	-1	-1	4.426
1700	16	130	1	-1	1	2.856
1700	18	110	1	1	-1	3.439
1700	18	130	1	1	1	2.668

The general formula for coding the variables in this table is actually quite simple. If L and U represent the lower and upper bounds of allowable values for a particular predictor variable and if V represents the uncoded value, the coded value C is defined as:

$$C = 2(V-(L+U)/2)/(U-L) \quad \text{or} \quad C = 2(V - \text{average})/\text{difference}$$

For example, the uncoded mean casualty rate of 1600 is equal to the coded value of:

$$C = 2(1600-(1600+1900)/2)/(1900-1600) = 2(1600-1750)/300 = -1$$

The uncoded CRAF capacity of 126 is equal to the coded value of:

$$C = 2(126-(110+130)/2)/(130-110) = 2(126-120)/20 = 0.6$$

Note that the mid-value of any uncoded variable is equal to a coded value of zero. The coded values make the manual calculations easier and enables curve fitting to be done using the method of orthogonal polynomials (25:229); however, general regression methods could also be used with the uncoded variables.

Parameter Estimation. The experimental design process concluded that the effects of each main factor, all two-way interactions, and the three-way interaction were significant in predicting the response variable value. A statistical package (BMDP) was used to estimate the coefficients of the polynomial terms using the method of least squares regression. The least squares estimators and regression statistics for the model are provided in Appendix C. The fitted linear regression model in the transformed response variable is:

$$\ln W = 3.033 + 0.309X - 0.18Y - 0.108XY - 0.326Z - 0.261XZ + 0.132YZ + 0.07XYZ$$

where W = the mean time in the system
X = coded mean casualty rate
Y = coded number of B-767 aircraft
Z = coded aircraft capacity.

The versatility of this equation can be shown in the following examples: To find the mean TIS when the mean casualty rate is 1800 per day and the capacity of each of 17 aircraft is 124, follow the three-step procedure:

1. Code (or transform) all known variables.

$$X = 2(1800-1750)/300 = 0.333$$
$$Y = 2(17-17)/2 = 0$$
$$Z = 2(124-120)/20 = 0.4$$

2. Substitute in the equation and solve for the unknown variable.

$$\ln W = 3.033 + 0.309(0.333) - 0.326(0.4) - 0.261(0.333)(0.4)$$
$$\ln W = 2.971$$

3. Decode (or transform) the result.

$$\ln W = 2.971$$
$$W = \exp(2.971)$$
$$W = 19.5 \text{ hours mean time in the system}$$

Therefore, under the conditions of the simulation model and the regression techniques, the patient's average time in the evacuation system is 19.5 hours. Algebraic manipulation of the equation's terms enables any of the independent variables to be determined given an average TIS and values for the other variables. Thus, if the aircraft capacity is known (say 118) and the analyst wants to know how many aircraft will be required if the mean casualty rate is 1680 per day and 20 hours mean TIS is assumed reasonable.

1. Code (or transform) the variables.

$$W = 20, \text{ therefore } \ln W = \ln(20) = 2.996$$
$$X = 2(1680 - 1750)/300 = -0.467$$
$$Z = 2(118 - 120)/20 = -0.2$$

2. Substitute and solve for Y.

$$\begin{aligned} 2.996 = 3.033 &+ 0.309(-0.467) - (0.18)Y - 0.108(-0.467)Y \\ &- 0.326(-0.2) - 0.261(-0.467)(-0.2) \\ &+ 0.132(-0.2)Y + 0.07(-0.467)(-0.2)Y \end{aligned}$$
$$.149Y = -0.067$$
$$Y = -0.449$$

3. Decode the variable.

$$2(V - 17)/2 = -0.449$$
$$V = 16.55 \text{ aircraft}$$

17 aircraft will be required under the given conditions; however, this example demonstrates the actual discontinuity of the independent variables even though the response surface is treated as a continuous surface. This does not cause problems as long as the results are interpreted correctly.

Because the number of aircraft and the aircraft capacity can assume only integer values, the response surface results must be rounded when solving for these variables.

Other Response Surfaces. Three additional response surface equations were generated using the same regression techniques; however additional simulation experiments were required. The regression results are provided in Appendix C for the response surfaces shown in Table VIII. The same procedures, outlined previously, apply; but, one must now have some idea of the number of aircraft operating in the system.

Table VIII

Linear Response Surfaces

Aircraft	Response Surface Equation
16	$\ln W = 3.212 + 0.429X - 0.448Z - 0.337XZ$
17	$\ln W = 3.028 + 0.336X - 0.343Z - 0.303XZ$
18	$\ln W = 2.861 + 0.202X - 0.201Z - 0.191XZ$

Using the same data as in the first example (1800, 17 and 124), the response equation corresponding to 17 aircraft yields a mean TIS of:

$$\ln W = 3.028 + 0.336(0.333) - 0.343(0.4) - 0.303(0.333)(0.4)$$

$$\ln W = 2.962, \text{ or } W = 19.3 \text{ hours}$$

The previous example resulted in a mean TIS of 19.5 hours. To see how both the two- and three-variable response surface equation compare with simulation experiments, assume the following parameter values for simplicity:

mean casualty rate = 1750 or coded value = 0
number of aircraft = 16 or coded value = -1
aircraft capacity = 130 or coded value = +1

Three-variable model yielded a mean TIS of 15.7 hours and the two-variable model yielded a mean TIS of 15.9 hours. A three replicate simulation average yielded a mean TIS of 14.8 hours. An interpretation in terms of the evacuation system will be provided in the next chapter; however, the somewhat higher predicted values indicate that a linear exponential expression may not be an appropriate functional form of the response surface.

Quadratic Models

In order to develop a quadratic functional form for the exponential model, simulation experiments were conducted at the midpoint values of each factor. Now however, since the design is no longer orthogonal, the coding of high and low values is not appropriate.

The only coding performed in developing a quadratic model was to divide the casualty rate factor by 100 and the aircraft capacity by 10. An example of a typical data point with this coding might be (16,18,11) corresponding to a casualty rate of 1600 and 18 aircraft with a capacity of 110.

Parameter Estimation. As in the linear model, a BMDP statistical package was used to estimate the coefficients of the quadratic polynomial. An "all subsets" regression was performed using all linear and quadratice main effects and all two-way interactions. The least squares estimators and regression statistics for the selected "best" subset are shown in Appendix C. The following quadratic regression model was determined:

$$\ln W = -2.98 + 2.095X - 1.81Z + 0.0613XX + 0.0966ZZ - 0.1078XY - 0.1833XZ + 0.1408YZ$$

where W = mean time in the system
X = casualty rate/100
Y = number of aircraft
Z = aircraft capacity/10.

The quadratic model has the same versatility as the linear model, but yields response surface values closer to the experimental results. The same treatment combinations as in the linear model will be used to compare the models. If the casualty rate is 1800 per day and each of 17 aircraft has a capacity of 124, the mean time in the system (TIS) is found by encoding, substituting and solving for W.

$$\ln W = -2.98 + 2.095(18) - 1.81(12.4) + 0.0613(18)(18) + 0.0966(12.4)(12.4) - 0.1078(18)(17) - 0.1833(18)(12.4) + 0.1408(17)(12.4)$$

$$\ln W = 2.7817$$

$$W = 16.15 \text{ hours mean TIS}$$

Other Response Surfaces. Again, as in the linear case, additional response surface equations were developed for the cases where the number of aircraft is known. Appendic C also contains the least squares estimators and regression statistics for these surfaces. Table IX summarizes the response surface equations.

Table IX

Quadratic Response Surfaces

Aircraft	Response Surface Equations
16	$\ln W = 3.100 + 0.0810XX + 0.1342ZZ - 0.2108XZ$
17	$\ln W = 2.751 + 0.0737XX + 0.1316ZZ - 0.1978XZ$
18	$\ln W = 2.546 + 0.0461XX + 0.0848ZZ - 0.1248XZ$

Model Comparisons

For the particular treatment combination of casualty rate = 1750, and each of 17 aircraft with capacity of 110, the five models (including a three-replicate average of the simulation model) produced the following mean TIS values:

Model	Mean TIS
Simulation Experiment	22.8 hours
Three-variable linear model	28.8 hours
Two-variable linear model	29.1 hours
Three-variable quadratic model	24.7 hours
Two-variable quadratic model	23.8 hours

The quadratic models are clearly more accurate than the linear models. Interpretation of these results in terms of the evacuation system will be included in chapter V. The functional form of the response surface equation that more accurately reflects the experimental results has been established. The results of the exponential equation with a quadratic polynomial exponent can be used to provide insight into the questions surrounding an "acceptable" evacuation and distribution system.

Summary

Applying response surface methodologies to the casualty evacuation simulation model has provided an efficient method for answering many questions pertaining to the effects the three independent variables have in the model. The examples presented in this chapter are some of the ways in which a response surface can be used to help analyze the real-world casualty evacuation problem.

The next chapter will examine the results of the simulation experiments and the response surfaces in terms of the system it simulates or describes. The versatility of the simulation model will be demonstrated and some observations on the system's structure and performance will be provided. Conclusions and recommendations will follow in Chapter VI.

V. EXPERIMENTAL RESULTS

Introduction

The research effort has progressed from the development of a casualty evacuation simulation model, to an experimental design process and finally to response surface methodology. Each step of the sequence has produced various kinds of data and relationships. This chapter will provide observations and explanations of the results from these developments.

The basic evacuation structure has been outlined in Chapter II and included the range of the independent variables and specific values for the simulation experiments. Chapter III established the statistically significant variables and fixed the values for other controllable factors. Response surfaces were generated in Chapter IV.

The analysis of results includes the simulation experiments conducted for some pilot runs and for those experiments that provided the response values used in the experimental design and response surfaces. Other explanations will include results from variations made to a base case model.

Simulation/Experimental Design Results

In addition to providing a means of model verification, preliminary simulation runs also helped establish a feeling for various measures of evacuation performance and a range of values for them. One early experiment did not differentiate between those patients offloading at the staging bases, those continuing to other U.S. cities, and those patients causing an overflow situation.

Though the overall mean time in the system (TIS) remained the primary measure of evacuation performance, the number of casualties in each category above and the maximum TIS for each category were important secondary measures that caused some model modifications. Originally, all aircraft were required to be fully loaded before departure. In some cases, this caused an excessive amount of overflow; therefore, C-9 aircraft are now permitted to depart at 75% capacity if less than a full load of casualties are waiting for transportation.

The pilot runs also pointed out specific treatment combinations resulting in grossly unacceptable mean TIS values. These results established bounds for the factors used in the experimental design process.

B-767 Utilization. Though the study did not intend to maximize B-767 utilization or optimize the number of aircraft required, high utilization rates were achieved in all but one treatment combination. A combination of low casualty rate and high capacity with 18 operating aircraft yielded a 70% utilization rate. All other design combinations resulted in utilization rates greater than 80%. Overcommittment of resources occurred when the system was saturated. This happened at only two design points - a high casualty rate and low capacity combination with either 16 or 18 aircraft.

C-9 Utilization. Though the experimental design process concluded that the number of C-9 aircraft was not statistically significant, the average C-9 utilization rate was between 70% and 80% when only six C-9 aircraft were exercised. When nine C-9 aircraft were used, the rate ranged from 50% to 65%. Six C-9 aircraft might be sufficient to

distribute casualties if an efficient CRAF scheduling policy is adopted and if potential patient overflow is not increased.

Such a policy would schedule a CRAF aircraft arrival only if at least three C-9 aircraft were available. This would maximize C-9 aircraft and aircrew utilization and minimize patient overflow situations described in chapter II. Determining a "best" scheduling policy as well as the optimum number of C-9 aircraft would require an additional study.

Maximum Time in the System

The meaning of maximum TIS should be explained again for emphasis. It includes the time a patient spends in flight, the ground time between aircraft transfers when necessary, the ground time for CRAF pre-departure activities and the time spent in the hospital awaiting transportation.

The actual maximum amount of time spent outside of the formal hospital environment for any patient is less than 18 hours. A two-hour bus or ambulance ride at final destination would increase this time to 20 hours. The expected time in transit is about 14 hours; therefore, the maximum amount of time spent waiting for transportation is 14 hours less than the maximum TIS.

Mean and Maximum TIS

Except in those situations with very little patient queueing, the maximum TIS value is approximately twice the mean TIS value. This is partly due to the first-in/first-out (FIFO) queue discipline of the model. Also, evacuation occurs at a fairly constant rate; therefore, the max TIS should be about twice the the mean TIS.

The convenient relationship between the mean and maximum TIS provides a useful method for determining an acceptable value for the primary response variable. This will be combined with the other measures of system performance to establish a realistic level of the mean TIS.

Criterion Value of Mean TIS

Selecting a value for the mean TIS will depend on its implications on whether the evacuation structure can handle the corresponding workload and if the values of the secondary measures of merit "make sense". Obtaining realistic values would require additional studies; however, for this research, subjective values will be used to simplfy the problem and to show how these secondary measures can be used to help establish a useful criterion value of mean TIS.

In addition to the mean TIS value, other important measures of performance include the maximum TIS and the maximum number of casualties awaiting airlift. Mean waiting time, number of overflow patients and average number of waiting patients must also be considered. Each analyst must determine a mean TIS criterion value to judge treatment combinations. What follows is one possible development an analyst can pursue and indicates some factors that must be evaluated in selecting a criterion value.

Based on the initial casualty distribution assumption that the highest casualty rate is 2500 per day, a maximum of 2500 patients waiting for transportation will be considered acceptable. If actual evacuation operations begin no later than 24 hours after the conflict starts, the five echelons of care should be capable of absorbing this many casualties.

A reasonable maximum waiting time for a patient could be 36 hours. When the expected in-transit time of 14 hours is added to this value, a maximum TIS of 50 hours would not be unrealistic. Based on the general relationship between mean and maximum TIS, a starting point for accepting or rejecting specific treatment combinations would be a mean TIS value of 25 hours.

If the number of overflow patients listed in Table I was not exceeded and the other measures of performance are acceptable, a response value of 25 hours would imply an acceptable factor combination. By combining all acceptable factor combinations, decisions concerning the number of aircraft to contract or how large a mean casualty rate the system could support can be made. A table of these results will be provided later.

Using the 25-hour criterion causes two of the experimental design treatments to be eliminated. A high casualty rate and low aircraft capacity combination results in large mean TIS values, excessive maximum TIS values, large numbers of waiting casualties and a large overflow population. Many other experimental runs are required to determine the mean TIS for values between the low and high limits of each factor in the design. The value of the response surfaces is clearly shown here; however, some interior values can still be simulated.

Midpoint Experiments

This section describes the results of the experiments conducted at midpoint values of the independent variables. Specifically, results from combinations of 17 CRAF aircraft with a 120-patient capacity and a

casualty rate of 1750 per day will be examined for data consistency and comparison with the linear response surface predictions.

The data in Table X summarizes all the treatment combinations possible using at least one midpoint value. Each entry is an average of three replicates of the simulation model. The raw data was used to develop the quadratic response surface equations.

Table X

Sample Mean TIS (Hours)

Casualty Rate	1600			1750			1900		
B-767 Capacity	110	120	130	110	120	130	110	120	130
16 CRAF	18.2	15.0	14.5	40.9	17.5	14.8	83.7	42.4	17.5
17 CRAF	15.4	14.6	14.2	22.8	15.3	14.6	55.3	24.6	15.3
18 CRAF	14.4	14.1	13.9	15.5	14.6	14.2	31.4	17.6	14.4

As expected, the increasing or decreasing trends were verified with these intermediate data points. This relationship can be useful in selecting or eliminating certain treatment combination easily. For example, since the average of three simulation experiments with the same treatment combination, say (1750,17,110), is less than 25 hours, then the result of decreasing the casualty rate, increasing the number of aircraft, or increasing the capacity would be less than 25 hours. If all other measures of performance were satisfactory, these "better" treatment combinations would also be acceptable.

It is useful to hold two of the independent variables fixed and observe the rate of change of the response variable as the third

independent variable changes. In some cases, the mean TIS appears to have a linear relationship, but a very non-linear relationship in other cases. This intuitive relationship strengthens the development of quadratic response surfaces.

Casualty Rate Experiments

The triangular distribution assumed at the beginning of the study was changed to see how other distributions affect the measures of performance. The base case triangular distribution had parameter values of (1000,1750,2500) resulting in a mean TIS of 16.7 hours in a system with 16 aircraft with capacity of 120. A Uniform(1000,2500) and a Normal(1750,250) were tested under the same conditions resulting in 19.9 hours and 15.6 hours respectively.

The apparent trend indicates that a distribution with a larger standard deviation results in a larger mean TIS when all other factors are held constant. In these cases, the standard deviations range from 250 for the Normal distribution to 433 for the Uniform; the triangular distribution standard deviation is 306.

Another variation in the casualty rate consisted of a cyclic generation of casualties. This might approximate the cycle between heavy combat losses and regeneration periods with few casualties. A 10-day cycle between successive high casualty rates beginning at a mean value of 1750 per day was examined. The sinusoidal function used to simulate the cycle is listed here and in the computer code.

Casualty rate = 1750 + 750*SIN(2*PI*DOW/10)

where DOW represents the day of the war.

This variation resulted in a mean TIS of 24.6 hours, an increase of eight hours. The patient queueing that results from heavy casualty rates required about two days of intensive evacuation operations to relieve the hospital congestion. The FIFO queue discipline causes a greater waiting time for those casualties generated on the "down-hill" portion of the cycle. However, the cyclic generation of casualties would probably be dampened somewhat as the casualties process through the four or five echelons of care before evacuation.

The 25-Hour Criterion

The level of this criterion was established subjectively, but based on reasonable levels of other measures of performance. Some treatment combinations that would be rejected according to this criterion might still considered acceptable in certain instances. This gray area consists of response values slightly greater than 25 hours, by one or two hours for instance.

One particular case had a mean TIS of 26.5 hours but at the 30-day point in the war, the mean TIS was 25 hours and all other measures of merit were within acceptable limits. A look at the system at the 30-day point is well after the initial surge period and sea lines of resupply will have been established. A decreasing C-141 resupply requirement suggests that if additional airlift could be committed at that time, additional treatment combinations could become feasible alternatives.

Patient Recovery Time

The base case model (1750,16,120) included a specific amount of hospital recovery time for each category of patient. Another variation of this model included increasing the recovery periods by 25%. The

result was an increase of the mean TIS to 20.1 hours. This reflects those situations when a hospital is full and remains full for a longer period thus requiring more and longer flights to other hospitals.

Minor overflow conditions were recorded at two of the staging bases that previously had none. The increased recovery times adversly affected the maximum TIS and maximum number of waiting casualties to the point where the treatment combination would be rejected. The maximum TIS increased from 31.3 to 56.3 and the maximum number in the waiting queue increased from 1080 to 2760. Though there is no reason to suspect the recovery time estimates, a marginally acceptable option could cause serious problems if the estimates are too low.

Response Surface Results

To avoid the costly and time consuming process of making additional simulation experiments, response surface equations were developed in chapter IV. Since the experimental design data points were used to determine the coefficients of the terms in the linear equations, the simulation results should be closely predicted by the linear response surface equations evaluated at those design points.

Simulation experiments were conducted at all combinations of midpoint values; quadratic response surface equations were developed from the results. The data in Table XI summarizes the average simulation results and predicted values from the three-variable quadratic equation. The error term measures the deviation from the predicted value.

Table XI

Comparison of Simulation and Response Surface Results

Treatment	Predicted	Simulated	Error
1600,16,110	18.8	18.2	- 3%
,120	14.3	15.0	+ 5%
,130	14.8	15.3	+ 9%
1600,17,110	15.7	15.4	- 2%
,120	13.8	14.6	+ 6%
,130	14.8	14.2	- 4%
1600,18,110	13.2	14.4	+ 9%
,120	13.4	14.1	+ 5%
,130	16.4	13.9	-15% *
1750,16,110	34.6	40.9	+18% *
,120	20.1	17.5	-13% *
,130	14.1	14.8	+ 5%
1750,17,110	24.7	22.8	- 8%
,120	16.5	15.3	- 7%
,130	13.4	14.6	+ 9%
1750,18,110	17.6	15.5	-12% *
,120	13.5	14.6	+ 8%
,130	12.6	14.2	+13% *
1900,16,110	84.1	83.7	- 1%
,120	37.1	42.4	+14% *
,130	19.8	17.5	-12% *
1900,17,110	51.0	55.3	+ 8%
,120	25.9	24.6	- 5%
,130	15.9	15.3	- 4%
1900,18,110	31.0	31.4	+ 1%
,120	18.1	17.6	- 3%
,130	12.8	14.4	+13% *

Some of the errors may seem unacceptably large in the table, but note the regions where the larger errors occur in terms of the mean TIS value. The largest errors correspond to treatments whose predicted mean TIS is below 20 hours or above 30 hours approximately. Based on the criterion value determined earlier (25 hours), the decision regarding

whether a treatment combination is accepted or rejected remains unchanged. Thus, the (1750,16,110) combination is rejected even though the prediction underestimates the simulated value; the (1900,16,130) combination is accepted even though the prediction overestimates the simulated value.

If an analyst selects a criterion value below 20 hours or above 30 hours, the problem would require re-examination of the evacuation structure and parameter values. Based on this study's structure and its measures of performance, such high or low criterion values appear unlikely.

Treatment combinations with predicted mean TIS values near 25 hours are within 10% of the experimental averages. Is this degree of predictive accuracy close enough? In an advanced planning situation with many assumptions and unknowns, the quadratic model can be used with confidence. It adequately measures the performance of a system described by the casualty rate, number of aircraft and aircraft capacity and operating according to this study's structure.

The response surface equations generally predict larger values than this particular sample. In other tests, the same relationship prevailed. The built-in conservative nature of the response surface equations provides a margin of safety for selecting viable treatment combinations.

Final Results

The examples in Chapter IV provide some idea of the kinds of questions that can be answered by using the response surface equations.

Given the model's parameters in this study and the 25-hour criterion value, the data that follows in Table XII will help answer the likely question: What are the upper limits of the mean casualty rate that a system comprised of X aircraft with capacity Y can evacuate?

Table XII

Three-variable Quadratic Response Surface Summary

Number of B-767	B-767 capacity	Casualty rate
16	110	1675
16	112	1700
16	114	1725
16	116	1755
16	118	1780
16	120	1810
16	122	1840
16	124	1870
16	125	1885
16	up to 130	1900
17	110	1750
17	112	1775
17	114	1805
17	116	1830
17	118	1860
17	120	1890
17	up to 130	1900
18	110	1850
18	112	1875
18	113	1890
18	up to 130	1900

Values greater than a mean of 1900 casualties per day could be evacuated but additional studies should be made on the tactical evacuation capabilities and the stateside distribution requirements. The table shows that for a fixed number of aircraft, the mean TIS increases by about 15 casualties per day per unit increase in aircraft capacity. Each aircraft is carrying one extra patient each day, approximately.

Summary

The simulation experiments provided various measures of system performance. High aircraft utilization rates were achieved at most operation conditions. With an intelligent scheduling algorithm for the CRAF operations, a C-9 operation with as few as six aircraft may be achievable.

A realistic maximum number of waiting casualties was established and a general relationship between mean and maximum TIS was observed. These provided an initial estimate of a decision or criterion value of the mean TIS.

This criterion value established a basis for comparing other treatment combinations. The effects of varying original parameters of the model (values and distributions) were judged according to the criterion value.

Simulation results were compared to the quadratic response surface predictions. The quadratic equations predicted values closer to the experimental results than the linear response surface equations.

The summary of results based on the model's assumptions, correction factor and criterion value for the mean TIS provides a guide for evaluating the performance and structure of the evacuation system envisioned. Conclusions and recommendations will follow in the last chapter.

VI. CONCLUSION

Review

The Casualty Evacuation Model (CEM) developed in this research effort began with the realization that the outcome of a conventional European conflict could be affected by the commitment of airlift resources to the evacuation mission. Current studies are evaluating the use of modified B-767 aircraft for casualty evacuation. This study has attempted to answer the question of how an evacuation and distribution network using B-767 and C-9 aircraft can be structured to perform the task and how its performance can be evaluated. A simulation model was developed to provide some answers and insight to the problem.

Structure

Though a 60-day conflict was used for the study, the structure of the network is essentially independent of the conflict's duration. The structure depends on casualty rates, numbers and types of aircraft involved, the number and location of operating bases, and many other factors.

Various casualty rates were examined in the study ranging from 1000 to 2500 per day. Two types of aircraft were considered in the evacuation plan, while the operating bases included one onload location, four staging bases and more than 40 offload locations in the eastern half of the U.S.

The B-767 aircraft performed the intertheater evacuation task and, when necessary, provided some distribution services. The C-9 aircraft operated from one location interfacing with the B-767s. With these

airlift resources, MAC would provide the link between the DoD Theater Combat Medical System and the National Disaster Medical System.

Four staging bases on the eastcoast - Boston, New York, Philadelphia and Washington - provide access to more than 25,000 hospital beds in more than 25 cities that may participate in the NDMS. The C-9 network, operating from Washington, provides access to more than 35,000 additional beds in 30 cities.

Performance

The primary measure of the system's performance is the amount of time a patient spends in the system. This time includes all flight times, predeparture ground times, and the time spent in the hospital waiting for transportation. Secondary measures of performance include aircraft utilization, average and maximum waiting times, average and maximum number waiting, and the number of overflow patients. Overflow patients are described in chapter II.

A value of 25 hours time in the system (TIS) was selected as the criterion value between accepting or rejecting a system's performance. The system is identified by its treatments (casualty rate, number of aircraft and aircraft capacity operating within the structure outlined above).

From the results of selected specific treatment combinations in the simulation model, response surfaces were developed to predict a performance value for treatment combinations that could not be simulated. The equations developed were conservative predictors of the mean TIS and thus provide a built-in margin of safety in estimating a system's performance.

Factors

The simulation model uses six factors to represent a specific evacuation network. The primary factors included the casualty rate, number of B-767 aircraft and the aircraft capacity. Predeparture ground times, flight times and the number of C-9 aircraft make up the other factors. All of the factors can be modified to accommodate many variations within the structure. Specific levels used in this study for each factor are described in chapter III.

Summary of Results

The research objectives in chapter I have been achieved. A routing structure was designed and tested in a simulation model under various operating conditions. The structure included the number and location of the necessary intermediate staging bases. For each factor combination, the number of B-767 aircraft required can be estimated and other measures of performance, particularly the mean time each patient spends in the system, can be determined.

Two types of model variations were examined. The first variations allowed changes to the three factors affecting the primary measure of performance. The second type of variation examined the effects of changes made to the model's assumptions and raw data estimates. The results from all variations were compared with a selected criterion value of 25 hours mean time in the system.

Specific values for each factor combination and variation are not as important as the degree and direction of change in the response variable. Generally, at low casualty rates, none of the variations caused an appreciable change in the mean TIS. At high casualty rates

and corresponding high mean TIS values, variations did not improve the value of mean TIS enough to cause a previously rejected factor combination to be accepted.

Factor combinations and variations resulting in a mean TIS between 20 and 30 hours constitute the gray area; however, the results have a consistent trend. A simulation experiment yielding 25 hours or less was found to be acceptable in all other measures of performance as well. A response surface prediction of 30 hours or less also had acceptable performance values.

Recommendations

The recommendations for further study deal primarily with the structure of the evacuation and distribution network. This study examined one feasible structure out of many possibilities and within this structure, other variations should be considered.

Excluding the tactical evacuation requirements, the first area that warrants additional attention is whether multiple onload locations should be incorporated into the simulation model. While flying time could be incorporated easily, specifying the number and location of additional onload bases and estimating the number of casualties departing each location could introduce more error than a single onload assumption. The multiple onload formulation also suggests an attemp to optimize the routing structure.

The choice of B-767/C-9 interface location should also be investigated. Washington was selected because, of the four staging bases, it was closer to the geographical center of the cities served by

the C-9 fleet. This city however, had a greater potential for a patient overflow problem.

These recommendations suggest formulating a scheduling policy to provide intelligent interface between the two types of aircraft. Without a realistic plan, the potential for overflow would increase.

The study suggested a 10% upward adjustment to the number of aircraft required to compensate for the lack of maintenance and weather delays and diversions. If these factors could instead be added to the simulation model, it would more closely represent the simulated real-world operation.

Final Remark

An optimal evacuation plan would be good to have, but not a necessity. The structure outlined in this research effort is one possible alternative that may warrant additional analysis. Its main concern has been the patient, measured by the TIS and average and maximum waiting times. These performance measures were translated into material resources required to achieve those desired standards.

The need for a casualty evacuation and distribution plan cannot be questioned, even one that is sub-optimal. A realistic, workable course of action affects the morale of the soldiers and their support from the people at home. The will to fight is one measure of a nation's war-fighting capability; thus actions that affect that willpower clearly affect the outcome of the conflict.

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Appendix A

SLAM Network Documentation

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GEN,WEWING,THESIS,10/22/85,,NO,NO,YES,NO,,132;
LIMITS,10,2,2000;
TIMST,XX(4),CRAF IN USE,8/10/1;
TIMST,XX(5),C9 IN USE,10/0/1;
TIMST,NNQ(2),WAITING.4.CRAF,20/25/25;
INTLC,XX(2)=0.0,XX(4)=0.0,XX(5)=0.0,XX(6)=12.0;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
; GLOBAL VARIABLES
; XX(1) = ONE-DAY CASUALTY RATE(X .1)
; XX(2) = DAY OF WAR(DOW)
; XX(3) = CASUALTY COUNTER(XX(3) < XX(1))
; XX(4) = NUMBER OF CRAF IN USE
; XX(5) = NUMBER OF C-9 IN USE
; XX(6) = CRAF CAPACITY(X .1)
; XX(7) = STAGING BASES: 3 = BWI, 4 = NYC, 5 = BOS, 6 = PHL
;
; ATRIBUTES
; ATRIB(1) = START TIME FOR PATIENT'S TIME IN SYSTEM
; ATRIB(2) = PATIENT CATEGORY
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
NETWORK;
       RESOURCE/CRAF(16),8;             NUMBER OF B767 AIRCRAFT
       RESOURCE/C9(9),9;                NUMBER OF C-9 AIRCRAFT
       CREATE,24,0,,60,1;               60 ONE-DAY TIME PERIODS
       ASSIGN,XX(1) = TRIAG(100.0,175.0,250.0,1),1;
; - - - - - - - - - - - - - - - -
; VARIATIONS FOR GENERATING CASUALTIES
;
;       ASSIGN,XX(1) = UNFRM(100.0,250.0,1),1;
;       ASSIGN,XX(1) = RNORM(175.0,25.0,1),1;
;       ASSIGN,XX(1) = USERF(1),1;
; - - - - - - - - - - - - - - - -
       ASSIGN,XX(2) = XX(2) + 1,XX(3) = 0.0,1;
EV7    EVENT,7,1;                       DAILY MTBED UPDATE
RTN    ASSIGN,XX(3) = XX(3) + 1,2;
          ACT,,XX(3) .LT. XX(1),RTN;    GENERATES DAILY CASUALTIES
          ACT;
       QUEUE(7);                        TEMPORARY HOLDING FILE
          ACT,23.9/XX(1);               RELEASES CASUALTIES FOR FLIGHT
       GOON,1;
          ACT/2,,.21,ASN1;CAT A CAS;    CAT 1 & 7 ARE 21% OF TOTAL
          ACT/3,,.41,ASN2;CAT B CAS;    CAT 2,3,8 ARE 41% OF TOTAL
          ACT/4,,.15,ASN3;CAT C CAS;    CAT 5,6,9,11 ARE 15% OF TOTAL
          ACT/5,,.23,ASN4;CAT D CAS;    CAT 4 & 10 ARE 23% OF TOTAL
; - - - - - - - - - - - - - -
;
; THIS SECTION ASSIGNS A CATEGORY TO EACH PATIENT
;
```

```
ASN1    ASSIGN,ATRIB(2) = 1.0;
           ACT,,,NXT;
ASN2    ASSIGN,ATRIB(2) = 2.0;
           ACT,,,NXT;
ASN3    ASSIGN,ATRIB(2) = 3.0;
           ACT,,,NXT;
ASN4    ASSIGN,ATRIB(2) = 4.0;
; - - - - - - - - - - - - - -
; THIS SECTION RELEASES ONE PLANE LOAD OF PATIENTS FOR FLIGHT
; AND CALLS EVENT 1 TO START THE CLOCK FOR TIME IN THE SYSTEM.
;
NXT     GOON,1;
           ACT,,NNQ(1) .GE. XX(6),EV1;
           ACT,,,HOP;
EV1     EVENT,1,1;
; - - - - - - - - - - - - - -
; THIS SECTION VERIFIES THAT A LOAD OF PATIENTS IS READY
; AND AT LEAST ONE CRAF AIRCRAFT IS AVAILABLE.
;
HOP     GOON,1;
           ACT,,NNQ(2) .GE. XX(6) .AND. NNRSC(1) .GE. 1,QUE;
           ACT,,,Q1;
QUE     QUEUE(10),,,,SEL;
; - - - - - - - - - - - - - -
; THIS SECTION ROUTES EVERY OTHER CRAF AIRCRAFT TO BWI
;
SEL     SELECT,,CYC,,QUE;
           ACT/20,,,PRI;ODD;
           ACT/1,,,SEC;EVEN;
PRI     ASSIGN,XX(7) = 3;
           ACT,,,EV2;
SEC     GOON,1;
           ACT,,.5,RGN4;
           ACT,,.2,RGN5;
           ACT,,.3,RGN6;
RGN4    ASSIGN,XX(7) = 4;
           ACT,,,EV2;
RGN5    ASSIGN,XX(7) = 5;
           ACT,,,EV2;
RGN6    ASSIGN,XX(7) = 6;
EV2     EVENT,2,1;
Q1      QUEUE(1);
        TERM;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       FLY CRAF TO FIRST DESTINATION HOSPITAL
;
ENT1    ENTER,1,1;
        AWAIT(8),CRAF/1,1;
        ASSIGN,XX(4) = XX(4) + 1.0;
           ACT,3.5;                         3.5 HOUR GROUND TIME BEFORE T.O.
        GOON,1;
           ACT/6,UNFRM(8.5,9.5,2),ATRIB(1) .EQ. 3.0,BWI;FLY TO BWI;
           ACT/7,UNFRM(8.0,9.0,3),ATRIB(1) .EQ. 4.0,NYC;FLY TO NYC;
           ACT/8,UNFRM(7.7,8.7,4),ATRIB(1) .EQ. 5.0,BOS;FLY TO BOS;
           ACT/9,UNFRM(8.2,9.2,5),ATRIB(1) .EQ. 6.0,PHL;FLY TO PHL;
```

```
BWI     EVENT,3,1;
        TERM;
NYC     EVENT,4,1;
        TERM;
BOS     EVENT,5,1;
        TERM;
PHL     EVENT,6,1;
        TERM;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       FLY CRAF TO EUROPE AND FREE
;
ENT2    ENTER,2,1;
           ACT/10,4.0 + UNFRM(7.0,8.5,6);TO EUR;4 HR GROUND + FLY TIME
        FREE,CRAF/1,1;
        ASSIGN,XX(4) = XX(4) - 1.0;
        TERM;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       FLY CRAF TO & FROM DESTINATION HOSPITAL
;            THEN RETURN TO EUROPE AND FREE
;
ENT3    ENTER,3,1;
           ACT/11,1.5 + ATRIB(1);CRAF TO H2; 1.5 HR CC,REFUEL + FLY TIME
        GOON,1;
           ACT/12,3.0 + ATRIB(1);CRAF FM H2; 3 HR OFFLOAD TIME + FLY TIME
        GOON,1;
           ACT/13,4.0 + UNFRM(7.0,8.5,7);TO EUR;4 HR CC,REF,MX + FLY TIME
        FREE,CRAF/1,1;
        ASSIGN,XX(4) = XX(4) - 1.0;
        TERM;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       FLY C9 TO DESTINATION HOSPITAL, RETURN AND FREE
;
ENT4    ENTER,4,1;
        AWAIT(9),C9/1,1;
        ASSIGN,XX(5) = XX(5) + 1.0;
           ACT/14,2.5 + ATRIB(1);C9 TO H2; 2.5 HR ONLOAD TIME + FLY TIME
        GOON,1;
           ACT/15,2.0 + ATRIB(1);C9 FM H2; 2 HR OFFLOAD TIME + FLY TIME
        FREE,C9/1,1;
        ASSIGN,XX(5) = XX(5) - 1.0;
        TERM;
; - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       COLLECT STATS FOR PATIENTS OFFLOADING HOSP.1 VIA CRAF
;
ENT5    ENTER,5,1;
        COLCT,INT(1),TIS.H1.CRAF,,1;
           ACT,,,H1;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR OVERFLOW PATIENTS
;
EN16    ENTER,16,1;
           ACT/16,,,OVER;BWI OVERFLOW;
EN17    ENTER,17,1;
           ACT/17,,,OVER;NYC OVERFLOW;
;
```

```
EN18    ENTER,18,1;
           ACT/18,,,OVER;BOS OVERFLOW;
EN19    ENTER,19,1;
           ACT/19,,,OVER;PHL OVERFLOW;
OVER    COLCT,INT(1),OVERFLOW,,1;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR ALL HOSP.1 PATIENTS
;
H1      COLCT,INT(1),TIS.HOSP.1,,1;
           ACT,,,AVG;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR PATIENTS OFFLOADING HOSP.2+ VIA CRAF/C9
;
ENT7    ENTER,7,1;
           ACT,2.5 + ATRIB(2);
        COLCT,INT(1),TIS.H2.CRAF.C9,,1;
           ACT,,,H2;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR PATIENTS OFFLOADING HOSP.2+ VIA CRAF
;
ENT8    ENTER,8,1;
           ACT,1.5 + ATRIB(2);
        COLCT,INT(1),TIS.H2.CRAF,,1;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR ALL HOSP.2+ PATIENTS
;
H2      COLCT,INT(1),TIS.HOSP.2,,1;
; - - - - - - - - - - - - - -
;       COLLECT STATS FOR ALL PATIENTS
;
AVG     COLCT,INT(1),AVERAGE,,1;
        TERM;
        ENDNETWORK;
INIT,0,1440;
SIMULATE;
FIN;
;
```

```
*     THESIS.FOR - 10/22/85
      PROGRAM MAIN
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET = 20000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END
******************************
*     DEFINITION OF VARIABLES
*
*     MTBED(I,J) = NUMBER OF EMPTY BEDS IN HOSPITAL J
*                  SERVED BY STAGING BASE I.
*     OUT(I,J,K) = NUMBER OF PATIENTS DISCHARGED ON DAY K
*                  FROM HOSPITAL J IN STAGING BASE AREA I.
*     FLYTM(I,J) = FLYING TIME FROM/TO HOSPITAL J
*                  TO/FROM STAGING BASE I.
*     FLY        = DUMMY VARIABLE FOR SELECTED FLYING TIME.
*     IDEST      = DUMMY VARIABLE FOR SELECTED DESTINATION HOSPITAL.
*     AREA       = ARRAY SUBSCRIPT FOR STAGING BASES.
*     HOSP       = ARRAY SUBSCRIPT FOR HOSPITALS.
*     DAY        = ARRAY SUBSCRIPT FOR DAY OF WAR.
******************************
* SUBROUTINE TO INITIALIZE ALL VARIABLES, CONSTANTS AND ARRAYS.
*
      SUBROUTINE INTLC
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      INTEGER MTBED,OUT,AREA,HOSP,DAY
      REAL FLYTM,FLY
      DO 120 AREA = 3,6
         DO 110 HOSP = 1,30
            MTBED(AREA,HOSP) = 0
            FLYTM(AREA,HOSP) = 0.0
            DO 100 DAY = 1,61
               OUT(AREA,HOSP,DAY) = 0
100         CONTINUE
110      CONTINUE
120   CONTINUE
*
```

```
*
*     BALTIMORE, WASHINGTON, RICHMOND
         MTBED(3,1) = 436
*     NORFOLK-VA BEACH, NEWPORT NEWS-HAMPTON
         MTBED(3,2) = 94
         FLYTM(3,2) = 0.5
*     PITTSBURGH
         MTBED(3,3) = 224
         FLYTM(3,3) = 0.6
*     BUFFALO
         MTBED(3,4) = 118
         FLYTM(3,4) = 0.8
*     SYRACUSE
         MTBED(3,5) = 42
         FLYTM(3,5) = 0.8
*     ROCHESTER
         MTBED(3,6) = 56
         FLYTM(3,6) = 0.8
*     ALBANY
         MTBED(3,7) = 74
         FLYTM(3,7) = 0.8
*     RALEIGH-DURHAM
         MTBED(3,8) = 61
         FLYTM(3,8) = 0.9
*     CLEVELAND
         MTBED(3,9) = 190
         FLYTM(3,9) = 0.9
*     COLUMBUS
         MTBED(3,10) = 83
         FLYTM(3,10) = 1.0
*     DAYTON
         MTBED(3,11) = 90
         FLYTM(3,11) = 1.1
*     DETROIT,FLINT,TOLEDO
         MTBED(3,12) = 426
         FLYTM(3,12) = 1.2
*     CINCINNATI
         MTBED(3,13) = 109
         FLYTM(3,13) = 1.2
*     LEXINGTON-FAYETTE
         MTBED(3,14) = 44
         FLYTM(3,14) = 1.2
*     COLUMBIA
         MTBED(3,15) = 44
         FLYTM(3,15) = 1.3
*     KNOXVILLE
         MTBED(3,16) = 51
         FLYTM(3,16) = 1.3
*     LOUISVILLE
         MTBED(3,17) = 88
         FLYTM(3,17) = 1.4
*     AUGUSTA
         MTBED(3,18) = 53
         FLYTM(3,18) = 1.4
*
```

```
*      INDIANAPOLIS
          MTBED(3,19) = 102
          FLYTM(3,19) = 1.4
*      GRAND RAPIDS
          MTBED(3,20) = 42
          FLYTM(3,20) = 1.5
*      ATLANTA
          MTBED(3,21) = 166
          FLYTM(3,21) = 1.5
*      NASHVILLE-DAVIDSON
          MTBED(3,22) = 99
          FLYTM(3,22) = 1.5
*      CHICAGO,GARY
          MTBED(3,23) = 671
          FLYTM(3,23) = 1.6
*      MILWAUKEE
          MTBED(3,24) = 140
          FLYTM(3,24) = 1.6
*      BIRMINGHAM
          MTBED(3,25) = 93
          FLYTM(3,25) = 1.7
*      JACKSONVILLE
          MTBED(3,26) = 55
          FLYTM(3,26) = 1.7
*      ST LOUIS
          MTBED(3,27) = 249
          FLYTM(3,27) = 1.8
*      MEMPHIS
          MTBED(3,28) = 110
          FLYTM(3,28) = 1.9
*      TAMPA,ORLANDO
          MTBED(3,29) = 206
          FLYTM(3,29) = 2.3
*TOTAL BWI AREA = 4216
*
*      NEW YORK, NEW HAVEN-WEST HAVEN, JERSEY CITY, NEW BRUNSWICK,
*      LONG BRANCH-ASHBURY PARK, PATTERSON-CLIFTON, NEWARK,
*      POUGHKEEPSIE, NEWBURGH-MIDDLETOWN, NASSAU-SUFFOLK
          MTBED(4,1) = 1342
*      MINNEAPOLIS-ST PAUL
          MTBED(4,3) = 186
          FLYTM(4,3) = 2.0
*      DES MOINES
          MTBED(4,4) = 40
          FLYTM(4,4) = 2.1
*      OMAHA
          MTBED(4,5) = 75
          FLYTM(4,5) = 2.3
* TOTAL NYC AREA = 1643
*
*      BOSTON, BROCKTON, HARTFORD, NEW LONDON-NORWICH, PROVIDENCE
          MTBED(5,1) = 441
*      KANSAS CITY, TOPEKA
          MTBED(5,4) = 157
          FLYTM(5,4) = 2.4
```

```
*     TULSA
         MTBED(5,5) = 55
         FLYTM(5,5) = 2.7
*     WICHITA
         MTBED(5,6) = 44
         FLYTM(5,6) = 2.8
*     OKLAHOMA CITY
         MTBED(5,7) = 129
         FLYTM(5,7) = 3.0
* TOTAL BOS AREA = 826
*
*     PHILADELPHIA, WILMINGTON, TRENTON
         MTBED(6,1) = 439
*     MOBILE, BILOXI-GULFPORT
         MTBED(6,3) = 51
         FLYTM(6,3) = 1.9
*     JACKSON
         MTBED(6,4) = 45
         FLYTM(6,4) = 1.9
*     LITTLE ROCK
         MTBED(6,5) = 68
         FLYTM(6,5) = 2.0
*     MIAMI, FT LAUDERDALE
         MTBED(6,6) = 257
         FLYTM(6,6) = 2.0
*     NEW ORLEANS
         MTBED(6,7) = 123
         FLYTM(6,7) = 2.2
*     SHREVEPORT
         MTBED(6,8) = 49
         FLYTM(6,8) = 2.3
*     DALLAS
         MTBED(6,9) = 219
         FLYTM(6,9) = 2.5
*     HOUSTON
         MTBED(6,10) = 244
         FLYTM(6,10) = 2.6
*     AUSTIN
         MTBED(6,11) = 26
         FLYTM(6,11) = 2.8
*     SAN ANTONIO
         MTBED(6,12) = 112
         FLYTM(6,12) = 2.9
* TOTAL PHL AREA = 1633
* GRAND TOTAL = 8318
      RETURN
      END
*
```

```
* * * * * * * * * * * * * * * *
*     MORE VARIABLES DEFINED
*
*     DOW  = DAY OF WAR (EQUIVALENCE XX(2)).
*     CITY = STAGING BASE (EQUIVALENCE XX(7)).
*     CAPY = CAPACITY OF CRAF(X .1)
*     RGN  = REGION FOR EACH STAGING BASE.
*     NRSC = NUMBER OF RESOURCES(SLAM VAR).
*     TMP  = DUMMY VARIABLE.
*     CAP  = C-9 CAPACITY(X .1)
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* EVENT SUBROUTINES
*
      SUBROUTINE EVENT(N)
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      EQUIVALENCE (XX(2),DOW)
      EQUIVALENCE (XX(6),CAPY)
      EQUIVALENCE (XX(7),CITY)
      INTEGER MTBED,OUT,AREA,HOSP,DAY,CAPY,RGN,NRSC,TMP,MTBD,CAP
      REAL FLYTM,FLY,CITY
      CAP = 4
      GOTO (1,2,3,4,5,6,7) N
* * * * * * * * * * * * * * * *
* EVENT 1
*
*     WHEN FULL CRAF LOAD IS AVAILABLE, REMOVE PATIENTS FROM FILE 1.
*
1     DO 130 IA = CAPY,1,-1
         CALL RMOVE(IA,1,ATRIB)
         ATRIB(1) = TNOW
         CALL FILEM(2,ATRIB)
130   CONTINUE
      RETURN
* * * * * * * * * * * * * * * *
* EVENT 2
*
*     DETERMINE DESTINATION REGION,
*     REMOVE PATIENTS FROM FILE 2 FOR FLIGHT,
*     FLY CRAF TO U.S.
*     FILE 3 = BWI,50% : FILE 4 = NYC,25%
*     FILE 5 = BOS,10% : FILE 6 = PHL,15%
*
2     RGN = INT(CITY)
      DO 140 IB = CAPY,1,-1
         CALL RMOVE(IB,2,ATRIB)
         CALL FILEM(RGN,ATRIB)
140   CONTINUE
      ATRIB(1) = RGN
      CALL ENTER(1,ATRIB)
      RETURN
```

```
* * * * * * * * * * * * * * *
* EVENT 3
*
*     PATIENTS AND CRAF HAVE ARRIVED AT BWI
*
*     FLY CRAF TO EUROPE AND FREE.
*     IF AT LEAST 75% OF ONE C-9 LOAD ARE IN FILE 3 AND
*        IF "SERCH" RETURNS WITH A DESTINATION HOSPITAL AND
*           IF AT LEAST 1 C-9 IS AVAILABLE THEN
*              REMOVE PATIENTS FROM FILE 3 (UPLOAD AIRCRAFT),
*              UPDATE MTBED AND DETERMINE DAY OF DISCHARGE,
*              FLY PATIENTS TO DESTINATION AND COLLECT STATS,
*              SCHEDULE C-9 FLIGHT,
*              CHECK FOR MORE PATIENTS,ETC;
*           ELSE OFFLOAD ALL REMAINING PATIENTS,
*        ELSE OFFLOAD ALL REMAINING PATIENTS,
*     ELSE OFFLOAD ALL REMAINING PATIENTS.
*
3     CALL ENTER(2,ATRIB)
      NRSC = NNRSC(2)
      TMP = CAPY
150   IF (TMP .GE. 3) THEN
         IF (TMP .EQ. 3) THEN
            CAP = 3
         ENDIF
         CALL SERCH(3,CAP)
         IF (IDEST .GE. 2) THEN
            IF (NRSC .GE. 1) THEN
               HOSP = IDEST
               DO 160 IC = CAP,1,-1
                  CALL RMOVE(IC,3,ATRIB)
                  CALL CASE(3,HOSP)
                  ATRIB(2) = FLY
                  CALL ENTER(7,ATRIB)
160            CONTINUE
               NRSC = NRSC - 1
               TMP = TMP - CAP
               ATRIB(1) = FLY
               CALL ENTER(4,ATRIB)
               GOTO 150
            ELSE
               CALL OFLD(3,TMP)
            ENDIF
         ELSE
            CALL OFLD(3,TMP)
         ENDIF
      ELSE
         CALL OFLD(3,TMP)
      ENDIF
      RETURN
* * * * * * * * * * * * * * *
* EVENT 4, 5, OR 6
*
*     PATIENTS AND CRAF HAVE ARRIVED AT NYC, BOS OR PHL.
*
```

```
*      IF AT LEAST "CAPY" EMPTY BEDS ARE AVAILABLE THEN
*         RETURN CRAF, OFFLOAD PATIENTS AND GET STATS,
*      ELSE FIND FIRST HOSPITAL WITH ENOUGH MTBEDS,
*         IF ONE IS FOUND THEN
*           SCHEDULE CRAF TO & FROM DEST HOSP, RETURN TO EUROPE,
*           REMOVE PATIENTS FROM FILE "AREA",
*           UPDATE MTBEDS AND DAY OF DISCHARGE,
*           FLY PATIENTS TO HOSPITAL, GET STATS.
*         ELSE OFFLOAD PATIENTS (POTENTIAL OVERFLOW)
*
4      AREA = 4
       GOTO 170
5      AREA = 5
       GOTO 170
6      AREA = 6
*
170    MTBD = MTBED(AREA,1)
       IF (MTBD .GE. CAPY) THEN
          CALL ENTER(2,ATRIB)
          CALL OFLD(AREA,CAPY)
       ELSE
          CALL SERCH(AREA,CAPY)
          IF (IDEST .GE. 2) THEN
             HOSP = IDEST
             ATRIB(1) = FLY
             CALL ENTER(3,ATRIB)
             DO 180 ID = CAPY,1,-1
                CALL RMOVE(ID,AREA,ATRIB)
                CALL CASE(AREA,HOSP)
                ATRIB(2) = FLY
                CALL ENTER(8,ATRIB)
180          CONTINUE
          ELSE
             CALL OFLD(AREA,CAPY)
          ENDIF
       ENDIF
       RETURN
* * * * * * * * * * * * * * * *
* EVENT 7
*
*      DAILY MTBED UPDATE
*
*      MTBED = EMPTY BEDS AT HOSPITAL DEFINED BY (AREA,HOSP)
*      OUT = NUMBER OF PATIENTS DISCHARGED FROM HOSPITAL ON A
*            SPECIFIED DAY OF THE WAR (DOW)
*
7      DAY = INT(DOW)
       DO 200 AREA = 3,6
          DO 190 HOSP = 1,30
             MTBED(AREA,HOSP) = MTBED(AREA,HOSP) + OUT(AREA,HOSP,DAY)
190       CONTINUE
200    CONTINUE
       RETURN
       END
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
*     SUBROUTINE OFLD REMOVES "NOFF" PATIENTS FROM FILE "AREA", UPDATES
*        MTBEDS AND COLLECTS STATS FOR ALL PATIENTS INCLUDING OVERFLOW.
*
      SUBROUTINE OFLD(AREA,NOFF)
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      EQUIVALENCE (XX(2),DOW)
      INTEGER MTBED,OUT,AREA,HOSP,DAY,NOFF,OVER,MTB
      IF (NOFF .LE. 0) THEN
         RETURN
      ENDIF
      MTB = MTBED(AREA,1)
*
*
      IF (MTB .GE. NOFF) THEN
         DO 210 JA = NOFF,1,-1
            CALL RMOVE(JA,AREA,ATRIB)
            CALL CASE(AREA,1)
            CALL ENTER(5,ATRIB)
210      CONTINUE
      ELSE
         OVER = NOFF - MTB
         DO 220 JB = MTB,1,-1
            CALL RMOVE(JB,AREA,ATRIB)
            CALL CASE(AREA,1)
            CALL ENTER(5,ATRIB)
220      CONTINUE
         DO 230 JC = OVER,1,-1
            CALL RMOVE(JC,AREA,ATRIB)
            CALL ENTER(AREA + 13,ATRIB)
230      CONTINUE
      ENDIF
      RETURN
      END
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*     SUBROUTINE CASE DECREASES THE NUMBER OF MTBEDS AND INCREASES THE
*        NUMBER OF PATIENTS TO BE DISCHARGED ON A PARTICULAR DAY OF
*        THE WAR (DOW) DEPENDING ON THEIR MEDICAL CATEGORY (ATRIB(2))
*
      SUBROUTINE CASE(AREA,HOSP)
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      EQUIVALENCE (XX(2),DOW)
      INTEGER MTBED,OUT,AREA,HOSP,DAY
*
*     UPDATE MTBED ARRAY
      MTBED(AREA,HOSP) = MTBED(AREA,HOSP) - 1
```

```
*
      IF (ATRIB(2) .EQ. 1.0) THEN
         DAY = INT(DOW + 16)
         IF (DAY .LE. 60) THEN
            OUT(AREA,HOSP,DAY) = OUT(AREA,HOSP,DAY) + 1
         ELSE
            OUT(AREA,HOSP,61) = OUT(AREA,HOSP,61) + 1
         ENDIF
      ELSEIF (ATRIB(2) .EQ. 2.0) THEN
         DAY = INT(DOW + 25)
         IF (DAY .LE. 60) THEN
            OUT(AREA,HOSP,DAY) = OUT(AREA,HOSP,DAY) + 1
         ELSE
            OUT(AREA,HOSP,61) = OUT(AREA,HOSP,61) + 1
         ENDIF
      ELSEIF (ATRIB(2) .EQ. 3.0) THEN
         DAY = INT(DOW + 38)
         IF (DAY .GT. 60) THEN
            OUT(AREA,HOSP,61) = OUT(AREA,HOSP,61) + 1
         ELSE
            OUT(AREA,HOSP,DAY) = OUT(AREA,HOSP,DAY) + 1
         ENDIF
      ELSE
         DAY = INT(DOW + 51)
         IF (DAY .GT. 60) THEN
            OUT(AREA,HOSP,61) = OUT(AREA,HOSP,61) + 1
         ELSE
            OUT(AREA,HOSP,DAY) = OUT(AREA,HOSP,DAY) + 1
         ENDIF
      ENDIF
      RETURN
      END
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*     USER FUNCTION ALLOWS CASUALTIES TO BE GENERATED IN A CYCLIC
*        PATTERN.  THIS EXAMPLE SHOW A 10 DAY CYCLE WHERE THE
*        QUANTITY 2*PI*10*DOW = ARGUMENT, 175 = EXPECTED VALUE AND
*        175 CORRESPONDS TO THE MAX DEVIATION FROM EXPECTED VALUE.
*
      FUNCTION USERF(I)
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      EQUIVALENCE (XX(2),DOW)
      GOTO (1) I
1     USERF = 175 + 175*SIN(0.6283*DOW)
      RETURN
      END
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*     SUBROUTINE SERCH FINDS THE NEAREST HOSPITAL WITH AT LEAST "BEDS"
*        NUMBER OF BEDS AVAILABLE WITHIN EACH AREA.  RETURNS WITH
*        HOSPITAL ID "IDEST" AND FLYTIME "FLY".
*
```

```
      SUBROUTINE SERCH(AREA,BEDS)
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      INTEGER MTBED,AREA,HOSP,BEDS
      REAL FLYTM,FLY
*
      IDEST = 1
      FLY = 0.0
      DO 240 HOSP = 2,30
         IF (MTBED(AREA,HOSP) .GE. BEDS) THEN
            IDEST = HOSP
            FLY = FLYTM(AREA,HOSP)
            RETURN
         ENDIF
240   CONTINUE
      RETURN
      END
******************************
      SUBROUTINE OTPUT
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      COMMON/MYVAR/MTBED(3:6,30),OUT(3:6,30,61),FLYTM(3:6,30),FLY,IDEST
      EQUIVALENCE (NSET(1),QSET(1))
      INTEGER MTBED,OUT
      REAL FLYTM,FLY
      RETURN
      END
******************************
```

APPENDIX B

POTENTIAL NDMS PARTICIPANTS

	CITY	ST	BEDS
1.	Mobile	AL	1325
2.	Birmingham	AL	3734
3.	Little Rock	AR	2752
4.	Phoenix	AZ	4100
5.	Tuscon	AZ	1659
6.	Riverside	CA	3758
7.	San Jose	CA	3353
8.	Sacramento	CA	1708
9.	Stockton	CA	654
10.	Santa Rosa	CA	542
11.	Los Angeles-Long Beach	CA	22600
12.	San Francisco-Oakland	CA	9273
13.	San Diego	CA	4766
14.	Anaheim-Santa Ana	CA	4430
15.	Denver	CO	5283
16.	New Haven-West Haven	CT	2443
17.	Hartford	CT	2332
18.	New London-Norwich	CT	421
19.	Washington	DC	8119
20.	Wilmington	DE	1544
21.	Ft Lauderdale	FL	3741
22.	Orlando	FL	2149
23.	Jacksonville	FL	2239
24.	Miami	FL	6559
25.	Tampa-St Petersburg	FL	6119
26.	Augusta	GA	2144
27.	Atlanta	GA	6657
28.	Des Moines	IA	1626
29.	Chicago	IL	24866
30.	Gary-Hammond	IN	1979
31.	Indianapolis	IN	4104
32.	Wichita	KS	1769
33.	Topeka	KS	677
34.	Louisville	KY	3559
35.	Lexington-Fayette	KY	1784
36.	New Orleans	LA	4924
37.	Shreveport	LA	1973
38.	Brockton	MA	576
39.	Boston	MA	12086
40.	Baltimore	MD	6447
41.	Flint	MI	1583
42.	Grand Rapids	MI	1682

43.	Detroit	MI	12968
44.	Minneapolis-St Paul	MN	7440
45.	St Louis	MO	9992
46.	Kansas City	MO	5628
47.	Biloxi-Gulfport	MS	754
48.	Jackson	MS	1819
49.	Raleigh-Durham	NC	2474
50.	Omaha	NE	3010
51.	Jersey City	NJ	1642
52.	New Brunswick	NJ	1321
53.	Long Branch-Asbury Park	NJ	1208
54.	Trenton	NJ	1184
55.	Patterson-Clifton	NJ	1177
56.	Newark	NJ	6689
57.	Albuquerque	NM	1508
58.	Las Vegas	NV	1174
59.	Poughkeepsie	NY	777
60.	Newburgh-Middleton	NY	772
61.	Buffalo	NY	4741
62.	Albany-Schenectady	NY	2973
63.	Rochester	NY	2258
64.	Syracuse	NY	1701
65.	New York	NY	31331
66.	Nassau-Suffolk	NY	6353
67.	Cincinnati	OH	4363
68.	Dayton	OH	3635
69.	Columbus	OH	3342
70.	Toledo	OH	2522
71.	Cleveland	OH	7622
72.	Oklahoma City	OK	3535
73.	Tulsa	OK	2223
74.	Portland	OR	3688
75.	Philadelphia	PA	14863
76.	Pittsburgh	PA	8969
77.	Providence	RI	2252
78.	Columbia	SC	1767
79.	Memphis	TN	4411
80.	Nashville-Davidson	TN	3961
81.	Knoxville	TN	2076
82.	San Antonio	TX	4505
83.	El Paso	TX	1647
84.	Austin	TX	1062
85.	Houston	TX	9790
86.	Dallas-Ft Worth	TX	8785
87.	Salt Lake City	UT	2205
88.	Richmond	VA	2878
89.	Norfolk-Va Beach	VA	2516
90.	Newport News-Hampton	VA	1244
91.	Seattle-Everett	WA	2998
92.	Tacoma	WA	1134
93.	Spokane	WA	1070
94.	Milwaukee	WI	5628

APPENDIX C

4 Factor Analysis of Variance for Mean Time in System (2 replicates).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Stat	Tail Prob
Cas	2.41501	1	2.41501	179.24	.00
Craf	1.25696	1	1.25696	93.29	.00
C9	0.02838	1	0.02838	2.11	.16
Cap	2.84214	1	2.84214	210.94	.00
Cas/Craf	0.53510	1	0.53510	39.71	.00
Cas/C9	0.00455	1	0.00455	.34	.57
Craf/C9	0.00617	1	0.00617	.46	.51
Cas/Cap	1.92624	1	1.92624	142.97	.00
Craf/Cap	0.84737	1	0.84737	62.89	.00
C9/Cap	0.00948	1	0.00948	.70	.41
Cas/Craf/C9	0.01464	1	0.01464	1.09	.31
Cas/Craf/Cap	0.30890	1	0.30890	22.93	.00
Cas/C9/Cap	0.00525	1	0.00525	.39	.54
Craf/C9/Cap	0.00316	1	0.00316	.23	.63
Cas/Craf/C9/Cap	0.01867	1	0.01867	1.39	.26
Error	0.21557	16	0.21557		

3 Factor Analysis of Variance for Mean Time in System (3 replicates).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Stat	Tail Prob
Cas	2.38442	1	2.38442	365.21	.00
Craf	0.77676	1	0.77676	118.97	.00
Cap	2.39895	1	2.39895	367.43	.00
Cas/Craf	0.31116	1	0.31116	47.66	.00
Cas/Cap	1.73454	1	1.73454	265.67	.00
Craf/Cap	0.41582	1	0.41582	63.69	.00
Cas/Craf/Cap	0.11174	1	0.11174	17.11	.00
Error	0.10446	16	0.00653		

Regression Statistics for Three-Factor Linear Model.

Adjusted Squared Mult. Corr.	.98535
Residual Mean Square	.00519
Standard Error of Est.	.07206
F-Statistic	221.96
Numerator Degrees of Freedom	7
Denominator Degrees of Freedom	16
Significance (Tail prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	3.03354	5.095	206.22	
Cas	0.309242	0.531	21.02	.282
Craf	-0.179915	-0.309	-12.23	.095
Cas/Craf	-0.108445	-0.186	- 7.37	.035
Cap	-0.325660	-0.559	-22.14	.312
Cas/Cap	-0.261037	-0.448	-17.75	.201
Craf/Cap	0.131528	0.226	8.94	.051
Cas/Craf/Cap	0.070496	.121	4.49	.015

Regression Statistics for Linear Model (16 aircraft).

Adjusted Squared Mult. Corr.	.98619
Residual Mean Square	.00758
Standard Error of Est.	.08707
F-Statistic	262.84
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	8
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	3.21243	4.335	127.80	
Cas	0.429063	0.605	17.07	.366
Cap	-0.447786	-0.631	-17.81	.398
Cas/Cap	-0.337070	-0.475	-13.41	.226

Regression Statistics for Linear Model (17 aircraft).

Adjusted Squared Mult. Corr.	.99421
Residual Mean Square	.00204
Standard Error of Est.	.04524
F-Statistic	630.28
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	8
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	3.02838	5.095	231.90	
Cas	0.336020	0.590	25.73	.349
Cap	-0.342767	-0.602	-26.25	.363
Cas/Cap	-0.303418	-0.533	-23.23	.284

Regression Statistics for Linear Model (18 aircraft).

Adjusted Squared Mult. Corr.	.96679
Residual Mean Square	.00437
Standard Error of Est.	.06614
F-Statistic	107.73
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	8
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	2.66087	7.883	149.85	
Cas	0.202296	0.582	10.60	.339
Cap	-0.200557	-0.577	-10.50	.333
Cas/Cap	-0.191466	-0.551	-10.03	.304

Regression Statistics for Three-Factor Quadratic Model.

Adjusted Squared Mult. Corr.	.95046
Residual Mean Square	.01125
Standard Error of Est.	.10606
F-Statistic	220.27
Numerator Degrees of Freedom	7
Denominator Degrees of Freedom	73
Significance (Tail prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	-2.979860	5.521	- .54	
Cas	2.095410	5.419	4.78	.014
Cap	-1.810300	-3.121	- 2.71	.005
Cas/Cas	0.061310	5.551	5.52	.019
Cap/Cap	0.096583	3.998	3.86	.009
Cas/Craf	-0.107817	-5.754	-12.75	.101
Cas/Cap	-0.183286	-7.943	-15.55	.150
Craf/Cap	0.140813	5.056	11.41	.081

Regression Statistics for Quadratic Model (16 aircraft).

Adjusted Squared Mult. Corr.	.95983
Residual Mean Square	.01476
Standard Error of Est.	.12151
F-Statistic	208.08
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	23
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	3.100320	5.114	12.78	
Cas/Cas	0.081006	5.839	11.27	.196
Cap/Cap	0.134249	4.423	8.78	.119
Cas/Cap	-0.210844	-7.273	-10.08	.157

Regression Statistics for Quadratic Model (17 aircraft).

Adjusted Squared Mult. Corr.	.97187
Residual Mean Square	.00522
Standard Error of Est.	.07226
F-Statistic	300.43
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	23
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	2.751400	6.386	19.07	
Cas/Cas	0.073736	7.478	17.25	.322
Cap/Cap	0.131641	6.103	14.48	.227
Cas/Cap	-0.197806	-9.601	-15.90	.274

Regression Statistics for Quadratic Model (18 aircraft).

Adjusted Squared Mult. Corr.	.86693
Residual Mean Square	.00845
Standard Error of Est.	.09190
F-Statistic	57.46
Numerator Degrees of Freedom	3
Denominator Degrees of Freedom	23
Significance (Tail Prob.)	.00000

Variable Name	Regression Coefficient	Stand. Coeff.	T-Stat	Contribution to R-Square
Intercept	2.545690	10.105	13.88	
Cas/Cas	0.046061	7.989	8.47	.368
Cap/Cap	0.084815	6.725	7.34	.275
Cas/Cap	-0.124824	-10.362	- 7.89	.319

VITA

Major William B. Ewing, Jr. was born on 22 October 1949 in Easton, Maryland. Upon graduating from SS. Peter and Paul HS in 1967, he attended Washington College in Chestertown, Maryland from which he received a Bachelor of Arts degree in Mathematics in 1971. After attending Officers Training School, he was commissioned in 1971 and attended Undergraduate Navigator Training at Mather AFB, California, receiving his wings in 1972. He was then assigned to the 30th MAS at McGuire AFB, New Jersey as a C-141 squadron navigator. He was assigned to fly C-130 aircraft at Kadena AB in Okinawa, Japan in 1974. Returning to the C-141 aircraft at McGuire AFB, he flew as an instructor navigator and also served as a 21st Air Force Flight Planner, Reports and Briefing Officer, Duty Controller and Aircrew Manager. He completed Squadron Officer School in 1979 and in 1980 was assigned to the 3rd MAS at Dover AFB, Delaware as a C-5 navigator, also serving as a Wing Command Post duty officer and Operations Resource Manager. In 1984, he attended the Air Force Institute of Technology, School of Engineering, Wright-Patterson AFB, Ohio from which he received a Master of Science degree in Operation Research (Strategic and Tactical Sciences) in March 1986.

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